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FIRE CONTROL TECHNICIAN 3

Prepared by

U.S. BUREAU OF NAVAL PERSONNEL

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PREFACE

This book is written as an aid in preparing Fire Control Technician strikers for promotion to the rate of Fire Control Technician 3. It is not enough for the striker to study only this text; he must also get practical experience in the operation and maintenance of fire-control equipment.

Before reading this volume, the striker should study the basic Navy Training Courses in mathematics and electricity. These basic training courses will give him the background necessary for understanding the material presented here, and will aid him later in the study of the advancement in rating manuals for Fire Control Technicians.

The material in this book has been organized into nine parts. The first four chapters are devoted to the fire-control problem and basic mechanisms. Chapter five covers gyroscopes, the principles of which are utilized in the chapter which follows on Lead-Computing Sights. The last three chapters discuss maintenance of fire-control circuits, synchro transmitters and receivers, and safety precautions.

Since men in the Fire Control Technician rating are becoming more and more a group of system or equipment experts, it is the present purpose to include more of the basic material which is applicable to all types of gear, rather than to emphasize a single system. When specific gear is described in the text, it is done chiefly for the purpose of applying certain basic fundamentals or to show the application of complex materials.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Training Publications Section in the Bureau of Naval Personnel and those naval establishments especially cognizant of the technical aspects of fire control.

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READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086 (or NavPers 10622–B until this is available)
Basic Hand Tool Skills, NavPers 10085
Basic Electronics, NavPers 10087
Blueprint Reading, NavPers 10077

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses fors additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Correspondence

Number	Title
CA 781	*Elementary Electricity*

Self-Teaching

Number	Title
MA 781	*Elementary Electricity*
MA 784	*Electric Wiring*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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STUDY GUIDE

Since this book has been written primarily for the FT General Service Rating, all its chapters are pertinent to the GSR. All or most chapters are also pertinent to the qualifications required for the emergency service ratings FTA, FTM, FTU, and FTG. The exceptions are that FTU3's may omit chapters 5, 6; and FTG3's may omit chapter 6.

FIRE CONTROL TECHNICIAN 3

CHAPTER 1

FIRE-CONTROL ORGANIZATION

THE FIRE CONTROL TECHNICIAN

Our Navy is only as strong as our ships, and a ship is only as strong as its *fire power*.

But fire power, to be effective, must be accurately controlled. This can be done only with the help of intricate machines—machines to sight on the target, to get the proper range, and to lay the gun to score a hit.

Stop and think for a moment how accurate these machines must be. Some modern 16-inch guns can shoot with deadly accuracy at 30,000 yards; and they can make it hot for the enemy at 40,000 yards (over 20 miles). Then, too, fast-moving air targets can be hit only if fire-control machines can solve the continuous changes of the gun's correct position with lightning speed.

Methods of automatically solving the gun's position were discovered during World War I. Naturally, the development of fire-control machines created a need for men to operate and maintain them; and so schools were set up to teach sailors how to obtain the new rating of Fire Control Technician. The first of these, the Seaman Gunner's School, was started at the Naval Gun Factory in Washington, D. C. This has grown into what is now known as the Fire Control Technician Schools, Class A and B, and you can look forward to attending them at least once during your Navy career.

As a Fire Control Technician you must first learn the problem of LAYING THE GUNS—the FIRE-CONTROL PROBLEM. But knowing the theory behind the problem is only part of your job. You'll have to acquire a great many new skills, both mechanical and electrical, in order to keep your gear in fighting trim.

You must be a mechanic so that you can maintain, adjust, and repair fire-control equipment. You must learn the principles of mechanics and how to use hand tools, gages, and instruments effectively. You must cultivate a sharp eye and a sure hand through actual on-the-job training.

You must be an electrician, for you'll be working with electronic circuits, electric motors, and switchboards. It's not enough to be an expert mechanic to operate these devices; you must know practical electricity as well.

You must become familiar with every knob, dial, and control at your battle station, for you'll be operating such mechanisms as directors, computers, fire-control switchboards, and radar.

The Fire Control Technician's job is man-sized in any language. It's a job not everyone can do because it takes a broad technical knowledge and a special type of know-how.

At times this book will get tough; but if you stick with it, and make the most of your practical experience aboard ship, you're bound to obtain the rate of Fire Control Technician 3. Next come Fire Control Technician 2 and then 1, and finally Chief Fire Control Technician. Then, if you've put your best into studying for and working in each rate, you may be recommended for gunner. It's a fine future, and it's yours— if you work for it.

ON THE JOB

Everyone wants to know what a job is like before he chooses it as his vocation. As you already know, fire-control equipment is maintained and operated by fire-control personnel. Every man in the fire-control division has a job to do; and whether it's small or large, every job is important.

Your duty as a Fire Control Technician 3 will be twofold; that is, you'll have both MILITARY and SPECIALTY duties. Every petty officer, regardless of specialty rating, will have the *same* military duties.

Your military duties consist of such tasks as watch

Figure 1-1.—Your twofold duties.

standing, guard duty, shore patrol, landing party exercises, and other similar jobs. Also, you'll be expected to know standard ship organization. You can learn all about this in the manual, *General Training Course for Petty Officers*, NavPers 10055, and from certain articles of *Navy Regulations*. Then, too, you'll learn what to do during emergency drills for fire, man overboard, repel boarders, and so on. All these are military duties.

As a petty officer (PO) you'll have to learn to receive and give orders cheerfully and willingly. You'll have to develop a personality that men like. No one likes a "hard head" and, moreover, no one likes to carry out such a man's orders. In short, you'll have to learn to get along with men to be a successful PO.

Another thing, always be sure your uniform and appearance are presentable. Never fail to look your best. The fire-control division is tops, and you must be on your toes to fit into it.

Your specialty duties will be those of a Fire Control Technician 3. These duties are set forth in this book. Briefly, these duties will be divided into two categories, namely, OPERATING and MAINTAINING fire-control equipment.

When general quarters (GQ) sounds, this means that you, like everyone else, must go to your battle station on the double. You will practice operating the fire-control gear at your battle station to keep in fighting trim.

Let's say that you have been assigned as a computer operator in the plotting room where the problem of laying the 5-inch guns is solved. When GQ sounds, you immediately rush to the plotting room, take your sound-powered battle telephones off the hook, strap them on, plug them into the proper jack, and take your place at the computer in front of the range dials and cranks. Speaking clearly over the phones you say, "all stations, plot testing." You hear the response from the various other talkers in the battery, and then turn to the plotting room officer or the Fire Control Technician in charge and say, "all stations manned and ready."

Everything is all right on your circuit, so you go about checking the computer to see that everything is properly set. All knobs are in the OUT position except Sync E knob which is in the IN position. You stand ready for a few seconds, and then things start humming. The ship's officers go into action and coordinate the practice of battle problems and tactics. Soon a target is sighted, and in a few seconds the director is on target. The pointer and trainer in the director close their respective keys, which, in turn, start the computer time motor and close a circuit to give you a continuous "Flag" on the computer which denotes that the director is still on the target.

Target angle dial will automatically rotate to its proper quadrant. The radar or rangefinder operator will close his key, which designates the proper range. You, as the computer operator, will match up the range dials and set the switch for automatic range.

One second later you have a solution and say to the plotting room officer "Solution Plot."

Now the control officer (located in the director) has been patiently waiting for these two words—seconds seemed like hours. Upon receipt of these words, assuming that everything else is set, the control officer gives the command, "COMMENCE FIRING!"

You hear the rumble of the 5-inch battery firing. You feel a slight shock at each salvo * * * but your eyes never move from the computer, range, elevation and bearing "Flags." You know that this is important because each time that a section of the computer deviates from solution, the shooting of the guns is in error.

Finally the word comes, "CEASE FIRING! * * * MISSION COMPLETED." The target is destroyed.

Everyone can relax now. A good job has been done, and you can smile and feel that you had an important part in it. You, as one of a team, have done your job correctly and properly * * * a grand feeling.

This is only one battle station to which you may be assigned. But it is typical of hundreds of others aboard ship and during your Navy career you may be rotated to many of them. Many Fire Control Technicians get good jobs in any one of several fields. You can do the same.

THE FIRE-CONTROL DIVISION

If you look around any combatant ship, you'll find plenty of fire-control gear. All of it is there to govern the guns, torpedoes, ahead-thrown weapons, depth charges, and rockets. However, don't get the idea that all equipment aboard ship is fire-control gear.

For example, in electronics there's radar for purposes other than fire control: some for search and some for navigation. Also, there's a maze of radio equipment for exterior communications. Then there are interior communication instruments such as telephones and public address systems. You could go on indefinitely naming different kinds of electronic

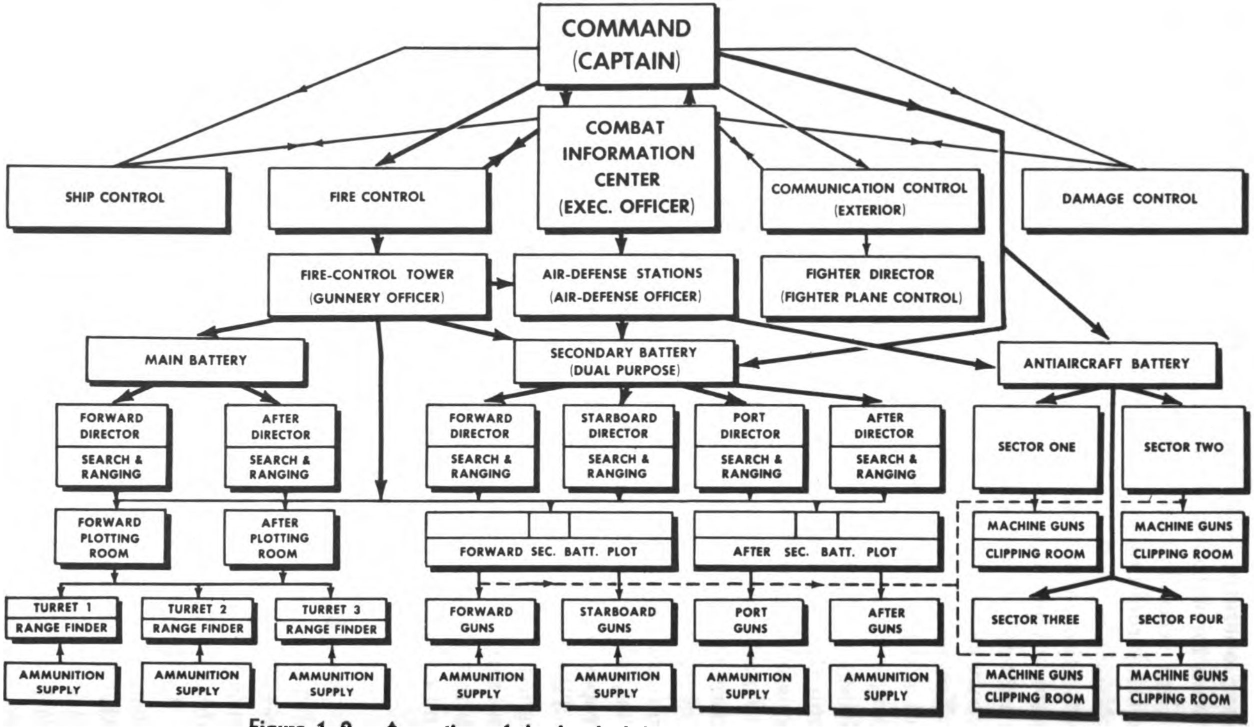


Figure 1-2.—A portion of the battle bill showing fire-control organization.

equipment—the Navy has them all. Every one of them is there to help produce the primary requisite of a combatant ship, effective fire power.

Think of the responsibilities of the captain of your ship; try to visualize him controlling the ship's fire with this maze of electrical and mechanical machinery. It would be impossible without the help of properly trained officers and men, working in a smooth-running and efficient organization.

For combat the organization of most fighting ships is broken down into four divisions: FIRE CONTROL, SHIP CONTROL, COMMUNICATION CONTROL, and DAMAGE CONTROL (fig. 1–2). These divisions, each of which is headed by an officer, should not be confused with STANDARD ship organization.

Figure 1–2 is a simplified flow diagram of the Battle Bill and is representative of battleship installations. Each of the main divisions functions under the captain through a chain of command like that illustrated for fire control.

To get the fire-control picture, follow the heavy lines and arrows in the figure. These lines show the chain of command and flow of combat information from various sources. The arrows pointing toward command indicate the route by which data is transmitted. The captain represents the ship; he is accountable for it. He is responsible for the operation and fighting efficiency of his ship; he is responsible for all members of his crew and all their acts. Since he is accountable for all that the ship does, for the quality of training aboard, and for the conduct of the crew at all times, he likewise is given full power to enforce *Navy Regulations* aboard the ship and to insure that the crew behaves accordingly. In short, since his responsibility is complete, his authority must also be complete.

Yes, the captain has a tremendous task—one that can be accomplished only with assistance. And that's why another agency, the COMBAT INFORMATION CENTER (CIC), is necessary.

The function of CIC is to help command plan the correct course of action, and to assist command and fire control in the execution of that plan. Primarily, CIC is an agency for the collection, evaluation, and distribution of combat information.

A quick solution of the fire-control problem is made possible by CIC. Often, before a target can be seen, CIC evaluates target information—course, speed, and range—and transmits this information to the plotting rooms through the gunnery officer.

But in order to accomplish all this, CIC must have keen eyes and ears. You've probably guessed already that CIC sees and hears by radar, sonar, and radio. Under the supervision of the CIC officer, usually the executive officer or an officer designated as the operations officer, information received from these sources is evaluated and relayed to the proper places.

Now go back to figure 1–2 and locate the fire-control block and the fire-control tower block. The fire-control tower is the battle station for the chief fire control officer, known as the gunnery officer. He heads three principal subdivisions: MAIN BATTERY, SECONDARY BATTERY, and the AA BATTERY.

Here again fingertip control of the three subdivisions is too much for one officer. And so the gunnery officer normally functions only as a supervisor of the air defense stations. However, he does maintain direct control of the main battery.

Air Defense

Air defense control is so complex that a special air defense officer is needed. The chief responsibility of this officer is coordinating the ship's defenses against aircraft so that the gunnery officer can give the ship's offensive weapons (main battery armament) his full attention.

Battery Control

In each director there is a group control officer. Under the supervision of the gunnery officer, with whom they are in direct communication, these group control officers are responsible for directing the fire-control problem. They communicate directly with the plotting rooms—also headed by an officer—to expedite the solution of the problem.

Then each turret has an officer called the turret officer. His duties are to supervise the gun crews, local fire-control gear, and the ammunition supply.

The whole setup is arranged for efficient and flexible control. For instance, the turrets can be controlled remotely from any director via any main battery plotting room. In case of emergency, each turret can be operated as a separate, independent unit.

There is no cut-and-dried rule to determine who will act as secondary battery control officer. Usually the assistant gunnery officer will act in this capacity. But often the secondary battery may be headed by the air defense officer if fire is being directed against air targets instead of surface craft.

As in the case of the main battery, the air defense stations may be controlled by an officer designated as a group control officer. For instance, each dual-purpose director may have an officer or senior petty officer in charge. Similarly, each sector (fig. 1–2) in the AA battery may have an officer-in-charge, headed by an AA battery officer. This affords greater flexibility and permits each group to operate independently in the event of an emergency.

There's one thing more about the air defense stations. Go back to figure 1–2 and see how CIC connects with the air defense stations, and how command connects with the secondary and AA batteries. It's important to remember that air targets don't fool around; they move in, attack, and are gone. For this reason command CIC must have direct communication with air defense to expedite defensive fire power.

Sector Control

For defense against air targets your ship will probably be divided into four sectors. These are shown in figure 1–3. Guns are assigned to cover each sector (look under AA battery, fig. 1–2) so that the ship may be fully protected at every angle.

In turn, the machine guns of each sector are concentrated as shown in figure 1–4. As shown in the example, the smaller machine guns (20-mm.) are divided in groups that cover

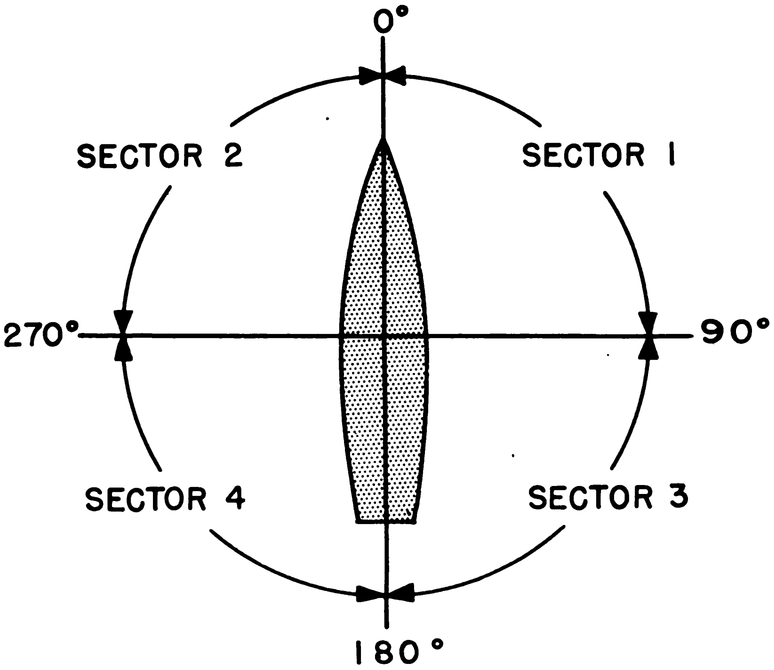


Figure 1–3.—Sector groups.

one-half of each sector. And the heavier machine guns (40-mm.) are divided to cover a whole sector.

Notice how the sectors overlap. This overlap is to insure coverage at the sector dividing points. Only sectors 1 and 2 are shown in figure 1–4, but sectors 3 and 4 are laid out in a similar manner.

In this setup many ships have a group control officer assigned to direct the activities of each group. He is responsible for the supervision of the particular sector assigned to that group.

He is also authorized to set fire doctrines and to designate targets required to keep attacking planes under fire. Also, assistant group control officers for each subsector are used. These assistants may be officers or petty officers regularly assigned to a gun of the subgroup.

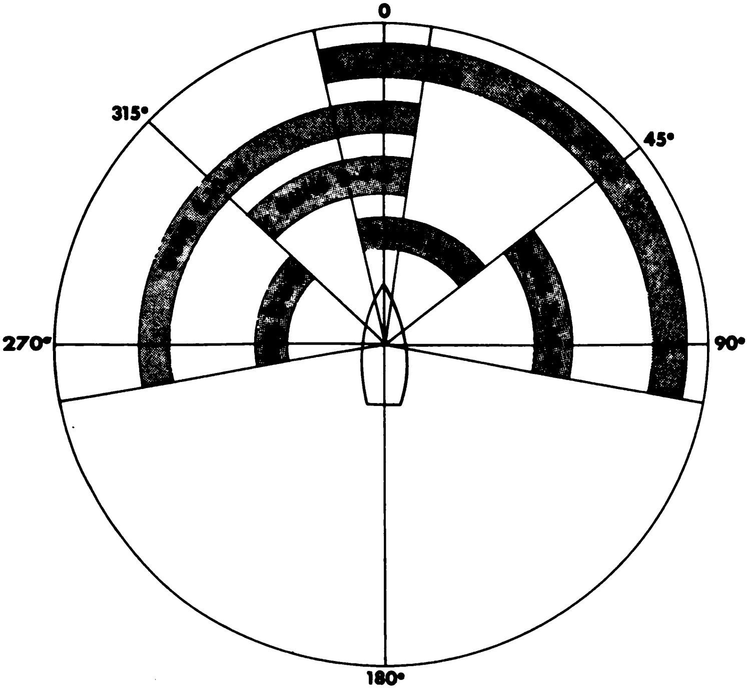


Figure 1–4.—Sector assignment of guns.

Summing Up

You've learned quite a lot about fire control already and there's plenty ahead. But get that organization down pat. Go back to figure 1–2 and give it one more look because you'll be referring to it throughout this book. It's important to fit each thing in as you go along. And you'll often find that figure 1–2 will be the answer to why fire-control gear is arranged as it is.

For example, look at the dotted lines in figure 1–2. These lines indicate that the heavy machine guns might be controlled from the dual-purpose plotting rooms. Well, sometimes they are. A selector switch in one of the plotting rooms does the trick. You'll find any number of combinations in figure 1–2 if you look for them.

Approximately the day you obtain your rating as Fire Control Technician 3, you'll be assigned a station in one of the batteries. It may be in the director as a pointer or trainer, or perhaps as a rangefinder or radar operator. If you end up in the plotting room, you may find yourself operating a computer, stable element or switchboard.

TAKE AN INVENTORY

Before tackling the fire-control problem, you must know the theories that govern fire-control machines and systems. You can't operate fire-control gear without having a sound background in the technical laws that govern it. That's why it's a good idea to stop at this point and take inventory of the things you DON'T KNOW.

You'll find that appendix IV will be of great use in taking stock of the gaps in your technical knowledge. This appendix lists practical factors and examination subjects contained in NavPers 18068. You should be thoroughly familiar with these before taking your examination.

Appendix IV will be a big help when it's time to take your examination. The lists will serve as a study guide and help you check subjects on which you need to brush up. The index will tell you where to find the qualifications discussed in this book.

WHERE TO STUDY

If your inventory of the things you don't know reveals that you need more basic study, you'll have to get other books.

The best and most useful books for this purpose are the BASIC NAVY TRAINING COURSES. These are the "blue covered" training manuals which serve three purposes: (1) they give you the background you'll need to prepare for a technical rating; (2) they offer a handy refresher course in subjects you may have forgotten; and (3) they are useful throughout all your Navy experience as a handy reference library.

Let's have a look at these books, and see what we can expect to find in them. They are listed as follows:

Mathematics, Vol. 1, NavPers 10069–A; Vol. 2, NavPers 10070–A
Blueprint Reading, NavPers 10077
Electricity, NavPers 10622–B
Basic Electronics, NavPers 10087
Basic Hand Tool Skills, NavPers 10085
Basic Machines, NavPers 10624

Basic Machines, NavPers 10624, will give you background for working with simple machines. This book covers such things as work, power, and force as applied to actual Navy gear. It starts from scratch and finally works into a discussion of electric, hydrostatic, hydraulic, and mechanical machines. Don't dodge this book. If you do, you'll be passing up a golden opportunity to build a sturdy foundation for future study and practical work.

From the very start of your work you'll be using hand tools, so don't lose any time in getting acquainted with the manual, *Basic Hand Tool Skills*, NavPers 10085. By using this and the manual on *Basic Machines* to supplement your practical experience, you should soon become a good mechanic.

Before mastering the fire-control problem and the computing devices that solve it, you must have a thorough knowledge of elementary mathematics, algebra, and trigonometry. You probably remember mathematics fairly well from high school, but since it's a subject on which anyone gets rusty rather fast, you'll need a review in it from time to time. *Mathematics*, NavPers 10069–A and NavPers 10070–A will give you a first-rate refresher course in mathematics. And if you haven't had trigonometry or algebra, it will tell you what you'll need to know about them.

Here's another manual you will need to KNOW—*Electricity*, NavPers 10622–B. It's a MUST—don't miss it. Like the other courses, it starts from very basic things by introducing a broad picture of electrical constituents of matter, and proceeds with a discussion of static electricity, electricity in motion, and electrical circuits. It explains the uses of Ohm's law and the power equations, and makes applications to actual circuits. Emphasis is placed on the various types of circuits—series, parallel, and series-parallel—and on the theory of induction as applied to electrical motors and apparatus. The essentials of generators and motors are fully explained. The closing chapters include a basic treatment of transformers, synchro units, electrical measuring instruments, and vacuum tubes.

There will always be times when you'll be called upon to do special repair work or trouble shooting. This type of work demands that you know how to read blueprints quickly and accurately. You're certain to run into several kinds of blueprints: schematic drawings, wiring diagrams, drawings of machined parts, isometric diagrams, and many others. Information with regard to the types of blueprints and how to read them can be found in the manual *Blueprint Reading*, NavPers 10077.

Another "must" manual is *Basic Electronics*, NavPers 10087, which presents most of the basic concepts in the field of electronics. Emphasis is placed primarily on the theory of operation of typical electronic components and circuits that have frequent application in naval electronic equipments. The description of specific equipments is left to your OP's, OD's and so on. This training course is intended as a basic reference for ALL enlisted personnel of the Navy whose duties require them to have a knowledge of the fundamentals of electronics. In some ratings, however, only certain chapters will be required reading. But, in your case (the FT)—all chapters are for you to study and the more familiar you are with this book, the easier it will be to progress up the ladder in the FT rating.

The Basic Navy Training Courses can be obtained from your education or division officer. Remember, the biggest part of knowledge is knowing HOW and WHERE to find it!

In addition, it is important to know your military duties as a petty officer. You can learn much about these duties in the *General Training Course for Petty Officers*, NavPers 10055. Part of your written examination for advancement will be based on this book, and therefore you should consider it is required review even though you may have a certificate of eligibility for PO completion in your record.

OTHER HELPFUL BOOKS

"Fundamentals first" is the rule for studying fire control, but if you want more detailed information on electricity, study *Electricity for Fire Controlmen and Fire Control Technicians*, Vol. 1, NavPers 10170, and Vol. 2, NavPers 10171. You could use NavPers 10170, Vol. 1, immediately after studying basic Electricity.

Another important thing to remember is that Ordnance Pamphlets, OP's and OD's, give you the word on specific fire-control gear. Whenever you're assigned to any particular gear, your first step is to familiarize yourself with the OP for that gear. As you become more skilled, OP's will become more helpful. Start on the right foot now. Don't guess—use OP's. OP 0 (zero) lists them all.

METHODS OF STUDY

There is only one way to study fire control: Learn the rules and find out how they apply to the problem. You will never become a Fire Control Technician if you simply memorize every electrical circuit and mechanical setup. You must understand WHY and HOW your gear works.

The purpose of this book is to help you do this.

But take the book in small enough doses to fit easily into your time schedule. It's better to read only a subheading at a time and understand it thoroughly than to skim through a chapter without absorbing the facts.

Don't neglect the diagrams. A good diagram can often be more valuable than a thousand words of description. After studying every section, take time off to think through what you have learned. Be sure you have the facts straight. If you're in doubt, go to your chief and ask him to help you. Never be afraid to ask questions. For in fire control more than in any other subjects, ignorance is not bliss. The wise Fire Control Technician ALWAYS knows his job.

QUIZ

Do you know what jobs the various officers on a ship perform? For each of the duties listed in column B, choose the man in column A who does the job. Write the letter only (a), (b), or (c), etc. on your answer sheet. You may use any of the job titles in column A MORE THAN ONCE.

COLUMN A

a. Air defense officer.
b. Group control officer.
c. CIC officer.
d. Gunnery officer.
e. Turret officer.

COLUMN B

1. Heads main, secondary, and AA batteries.
2. Supervises gun crews.
3. Supervises evaluation and distribution of information.
4. Supervises use of local fire-control and ammunition supply.
5. Responsible for directing fire-control problems.
6. Coordinates ship's defenses against aircraft.
7. Supervises local fire-control gear.
8. Supervises air defense.

In the following questions, select the answer (a), (b), (c), or (d) that BEST completes the statement or answers the question.

9. Which of the following is NOT a MAIN division of usual combat ship?
   a. Fire Control
   b. Ammunition Control
   c. Ship Control
   d. Damage Control
10. Which of the following is NOT a PRIMARY function of the CIC?
   a. Assist command in planning a correct course of action
   b. Collect, evaluate, and distribute combat information
   c. Assist command and fire control in carrying out course of action
   d. Direct fire-control problem arising under combat conditions

11. Who usually serves as the CIC officer?
  a. Executive officer
  b. Group control officer
  c. Gunnery officer
  d. None of the above

12. The chief fire control officer is the
  a. CIC officer
  b. gunnery officer
  c. group control officer
  d. executive officer

13. Where is the chief fire control officer stationed?
  a. In the plotting room
  b. With the captain
  c. In the fire-control tower
  d. At the director

14. The chief fire control officer normally has direct control over the
  a. main, secondary, and AA batteries
  b. secondary and AA batteries only
  c. main and secondary batteries
  d. main battery only

15. Where is the group control officer usually stationed?
  a. At the director
  b. At the main battery
  c. At the main turret
  d. In the plotting room

16. The group control officer is directly responsible to the
  a. chief fire control officer
  b. executive officer
  c. captain
  d. CIC officer

17. A combat ship is generally divided into how many sectors?
  a. 2
  b. 3
  c. 4
  d. None of the above

18. A ship is divided into sectors to provide for
  a. breakdown of responsibilities
  b. sufficient groups for training purposes
  c. administrative jurisdiction over personnel
  d. protection at every angle

It's important that you know where to look for background material for your job as a Fire Control Technician. There are several Navy textbooks which will be very helpful. For each of the items listed in column B, select the book from column A that would be MOST USEFUL. Just write the letter on your answer sheet. You may use the items in column A as many times as necessary.

COLUMN A

a. *Basic Machines,* NavPers 10624.
b. *Basic Hand Tool Skills,* NavPers 10085.
c. *Mathematics,* NavPers 10070-A.
d. *Electricity,* NavPers 10622-B.
e. *Blueprint Reading,* NavPers 10077.
f. *General Training Course for Petty Officers,* NavPers 10055.

COLUMN B

19. Trigonometry.
20. Generators and motors.
21. Work, power, force, and pressure as applied to Navy gear.
22. How to use hand tools.
23. Electric and hydraulic machines.
24. Ohm's law.
25. Electrical circuits.
26. Reading diagrams.
27. Military duties of a rated Fire Control Technician.
28. Transformer and vacuum tubes.

CHAPTER 2

PREVIEW OF THE FIRE-CONTROL PROBLEM

INTRODUCTION TO FIRE CONTROL

LAYING THE GUN is the process of training and elevating it to a position where it will score hits. That sounds as simple as shooting sitting ducks. But, when you consider a few of the complications, you'll find that it's more like shooting ducks in flight from a row boat in a rough pond.

In the first place, it is likely that the target will be maneuvering continuously, and that makes your fire-control prob-

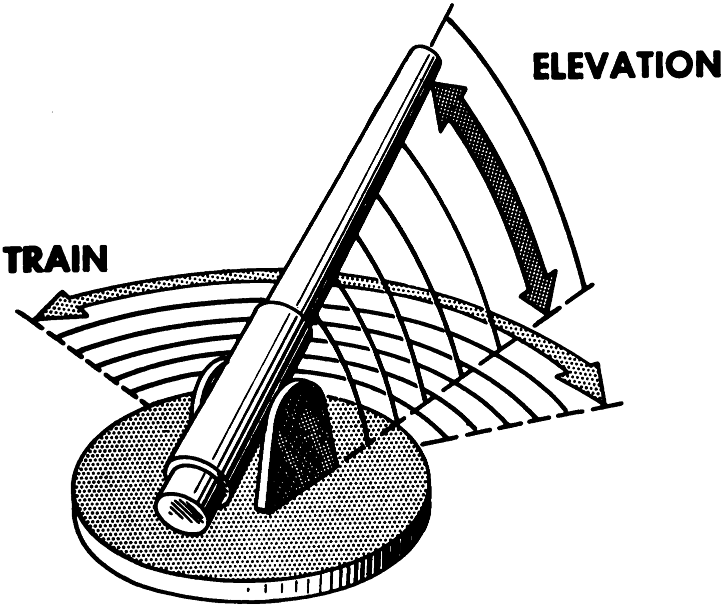


Figure 2-1.—Train and elevation angles.

lem difficult. That means the gun must LEAD the target by a certain angle in order to score hits.

Think of shooting at a target 15 miles away. A 16-inch projectile takes almost a minute to get to such a target from the time it leaves the muzzle of the gun. Then, if the target is making 40 knots, it will have moved about 1,300 yards by the time the projectile arrives—a sure miss unless the gun is laid to lead the target by the correct angle.

In fire-control terms, if the target is moving left or right, the gun TRAIN ANGLE will have to be corrected. Or if the target is moving toward or away from your ship, the gun ELEVATION ANGLE will have to be corrected. You can see these train and elevation angles in figure 2–1.

To complicate the problem even further, your own ship isn't going to be swinging around the "hook"; it, too, will be moving. Also, your ship will be rolling and pitching as a result of ocean ground swells and waves. Therefore, the gun angles will have to be automatically corrected for own ship's motion and, at the same time, for roll and pitch of the ship.

The Projectile

Then there are other things to consider. As the projectile speeds toward the target the force of gravity pulls it down, its spin pushes it sideways like a curving baseball, the wind shoves it one way or the other, and air resistance slows it down. Yes, more corrections to gun train and elevation are necessary.

However, calculating these corrections is not an impossible problem; it's being done right along. Each type of gun is tested at the Naval Proving Grounds where a study of these latter effects are made for different gun elevation angles and ranges (distance from gun to target). Then the necessary corrections are calculated and entered on range tables. From these tables rangekeepers and computers are built to solve the gun train and elevation corrections continuously and automatically.

You'll learn a lot about rangekeepers and computers later in your career. These problem solvers are located in the plotting room.

Directing the Guns

The gun director is the part of a fire-control system which serves as the "eyes" of the system.

The director tracks and sights on the target and measures target bearings, elevation, and range. This information is transmitted to the plotting room where the problem is solved. Finally the train and elevation angles are transmitted so as to position the guns. Briefly, that is what happens in main battery and dual-purpose fire-control systems.

The director is mounted on a high point on the ship such as that shown in figure 2–2, and the computing mechanisms are located in the plotting room below decks. The guns and mounts are mounted at various points on the main deck and superstructure.

At the director the radar and rangefinder measure the distance or range to the target. At the same time the director train angle and sight depression angle measure the target bearing and elevation. This information is fed to

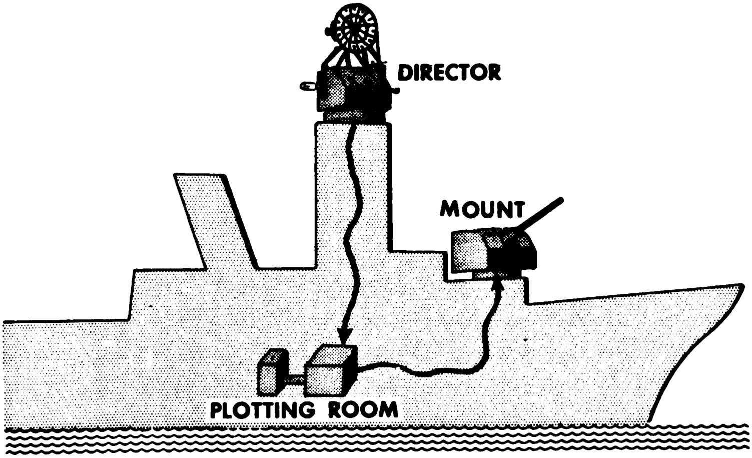


Figure 2–2.—Fire-control system.

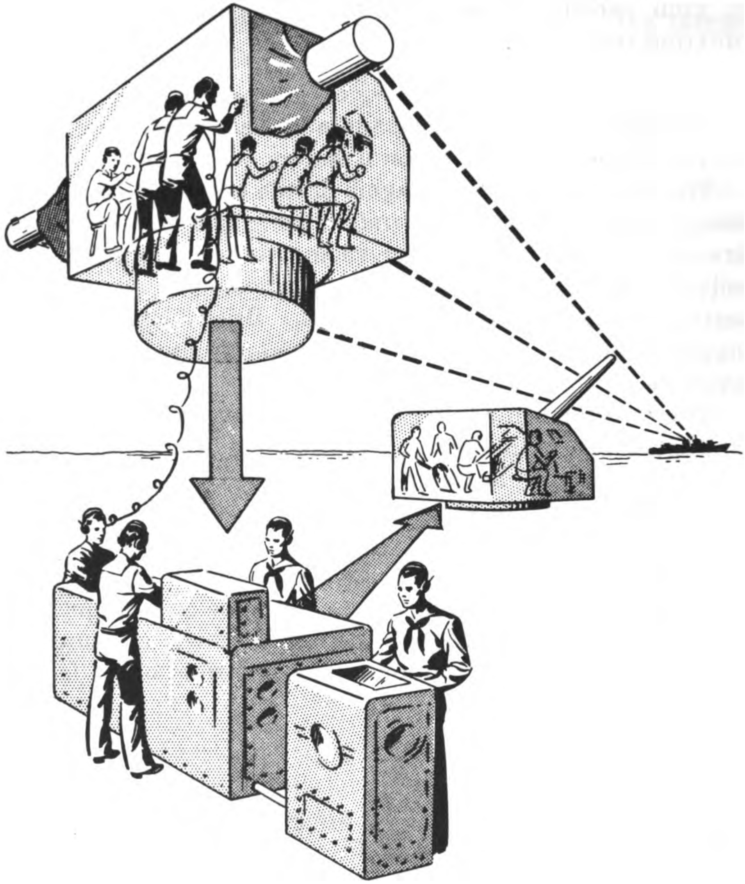


Figure 2–3.—Controlling the guns.

the computer where the corrections and lead angles are computed. Finally, the computer outputs—corrected gun train and elevation—are continuously fed to the gun.

Each gun or turret has its own power drives—one for train and one for elevation—which do the positioning automatically in response to the computer's outputs.

Notice the stable element in figure 2–3 (foremost instrument). It continuously feeds corrections for roll and pitch to the computer by means of mechanical connections. That means the gun orders (train and elevation) are corrected continuously also for roll and pitch.

GENERAL DESCRIPTION

Up to now you've learned something about the fire-control organization, a little about laying the guns, and something about a typical fire-control system. That gives you a glimpse of the whole fire-control picture—enough to know what to look for. Now is the time to inspect some of the equipment.

First, go up to the director and look around. Inspect the radar, rangefinder, and director sights.

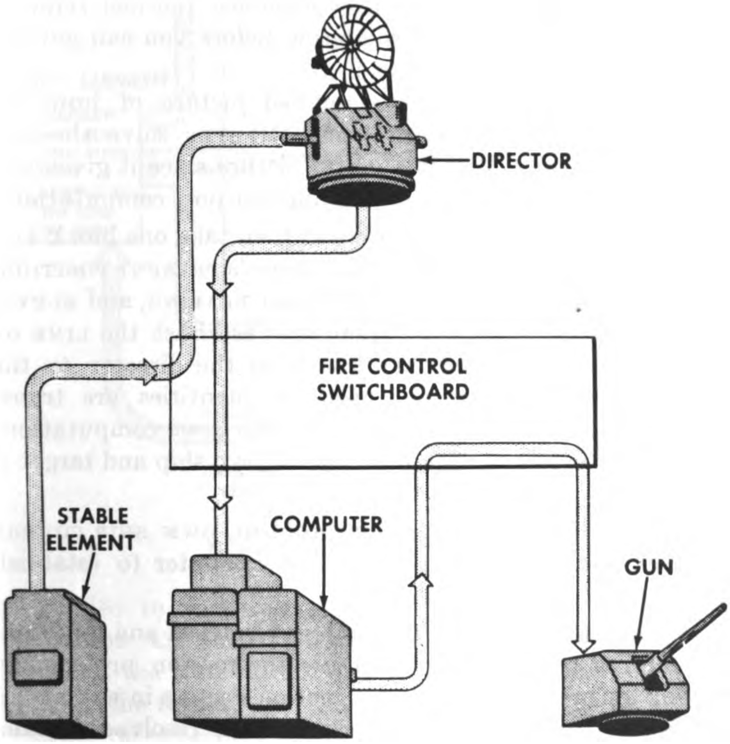


Figure 2–4.—The electrical tie-in.

Then visit the plotting room. Locate the computer or rangekeeper, the stable element, and the fire-control switchboard. Examine them closely.

Next look over the turrets and guns. Inspect their sights, loading mechanisms, and local fire-control gear.

Finally, look at figure 2–4 to get the whole picture. The arrows in the figure indicate the electrical ties between the director, fire-control switchboard, computer and gun.

SOLVING THE PROBLEM

By this time you should have a fairly good picture of the fire-control system and its layout as a whole—enough to make you inquisitive about how the fire-control problem is solved. Although you've learned about own ship and target motion and the lead angles they generate, the fact remains that these things need consolidating before you can get the overall picture. That comes next.

Figure 2–5 presents a streamlined picture of how the DIRECTOR, STABLE ELEMENT, and COMPUTER solve the fire-control problem. This is a useful picture since it gives you the basis for all main battery and dual-purpose computations.

First, get the overall picture and then take one block at a time. The director measures the target's PRESENT POSITION. This includes RANGE, RELATIVE TARGET BEARING, and ELEVATION. In turn, these three quantities establish the LINE OF SIGHT—a straight imaginary line from the director to the target. The three present position quantities are transmitted to the computer to enter into the basic computations where the relative motion problem for own ship and target is solved.

In order to solve the motion problem, OWN SHIP COURSE and SPEED also must enter into the computer to establish a stable plane for computations.

From this information the various electrical and mechanical units of the computer compute the motion problem by solving for own ship and target motion vectors in and across the line of sight. These vectors are then resolved (broken down into right angle components), and their components

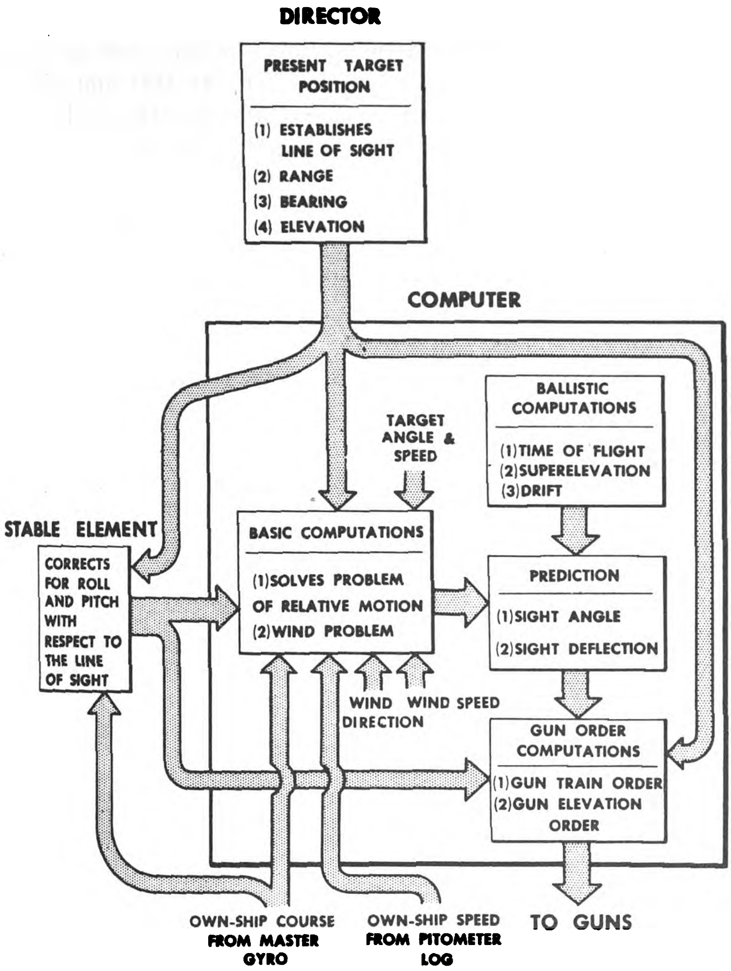


Figure 2–5.—Solving the problem.

are added to make up BEARING RATE, RANGE RATE, and ELEVATION RATE. By definition, these quantities simply represent the time rate of change in bearing, elevation, and range of the target.

These rates become the inputs to the prediction section of the computer and are MULTIPLIED by TIME OF FLIGHT to form the basic prediction of where the target will be time-of-flight seconds later. As you can see from figure 2–5, time of flight is determined in the ballistic section—ballistic here meaning gun correction. Also, such corrections as drift and superelevation (correction for trajectory) add into the prediction, and are also manufactured in the ballistic section. The prediction section of the computer winds up by calculating SIGHT ANGLE and SIGHT DEFLECTION. Sight angle includes the elevation lead angle and all corrections that enter into gun elevation. Sight deflection includes the bearing lead angle as well as all corrections, such as drift, that add into the gun train angle.

Finally, sight angle and sight deflection are treated by the stable element correction angles, and then are added to the director (target) bearing and elevation angles to make up the GUN ORDERS. The gun orders include among others the GUN TRAIN ORDER and the GUN ELEVATION ORDER. Train order positions the gun in bearing, whereas elevation order positions the gun in elevation.

Now tie together the loose ends at the various blocks in figure 2–5. Notice the arrows leading to the basic computation section. Target angle and speed are often cranked in by hand to expedite the solution of the problem. However, most machines can solve for target angle and speed automatically.

Then there are the WIND INPUTS—WIND DIRECTION and SPEED. They are cranked in manually and resolved into components in and across the line of sight, much the same as the motion problem. They are then used in the prediction section for the calculation of the gun order.

The stable element manufactures the roll-and-pitch correction angles in and across the line of sight. Consequently, the line of sight must be corrected by the stable element. This is accomplished by transmitting the director train angle (the relative target bearing as measured at the director) to the stable element. Then the stable element does the rest. Own ship's course is required for another correction. This correction is also made by the stable element. (You'll learn more about the stable element in a later course.)

It is realized that the above explanation is brief but it will give you a complete circuit of thought—an extremely important one. If you haven't got it straight, go back to figure 2–5 and really study it. Then you'll be thoroughly prepared for the following chapters.

ACCURACY AND PRECISION

Your study thus far indicates that the fire-control system is quite unique in purpose and layout. On the other hand, you probably observed that the instruments that go to make up the system are constructed of many component parts, some already familiar to you.

These component parts—BASIC MECHANISMS—compute the fire-control problem from the various measurements taken at the director. The computer or rangekeeper is the heart of every fire-control system, so we'll cite it as an example. It's composed of multipliers, vector solvers, component solvers, component integrators, computing cams, ballistic cams, and a multitude of similar devices all of which must be precision built, and at the same time must work with a minimum of friction. In short, every basic mechanism, shaft, and gear must be accurate in design and structure.

Several individual computations and measurements go to make up gun elevation orders, and errors accumulate or multiply. Hence, the accuracy of each individual computing or measuring device must be even greater than the accuracy of the final product, in this case, the gun elevation order. Moreover, each adjustment you will perform as a technician must be accurate. It won't take many small errors in the adjustment of computing mechanisms to cause a large error in the output like the one cited above for gun elevation order.

A later course will be devoted to a detailed coverage of the construction, operation, and adjustment of the various basic mechanisms. Wherever possible, an application of the unit will be discussed. However, before you can really learn how these basic mechanisms work together to solve the fire-control problem, you'll have to know the problem itself.

To sum up, accuracy is achieved by the use of precision-built parts and precision-built instruments, and by making precise adjustments.

THE "INNARDS"

Before you study the following chapters, it would be well to get an idea of what types of equipment compose the "innards" of fire-control instruments. Fire-control gear can be broken into five basic categories, namely: MECHANICAL, HYDRAULIC, OPTICAL, ELECTRICAL, and ELECTRONIC.

Some of the things you'll encounter under the heading of mechanical gear will be precision drives, computing mechanisms, and gyros. Precision drives position the guns, sights and computing mechanisms; whereas computing mechanisms, as you've learned, compute the gun orders. You'll find gyros in stable elements, stable verticals, certain fire-control directors, and in lead computing sights.

Hydraulic power drives train and elevate the guns in accordance with the computer's outputs. You'll see them used to drive 40-mm. quad. mounts and 5"/38 guns or larger.

Taking care of the optics is no longer a part of your job—except for routine cleaning. The opticalman will maintain, repair, and overhaul your binoculars, telescopes, turret and submarine periscopes, rangefinders, lead-computing sights, and optical gun sights.

Such devices as synchros (self-synchronous motor-like devices used to transmit angular motion or displacement from one station to another), follow-up motors, and various electrical power drives will come under the heading of electrical gear. Some of these devices will also be covered in the FT2 course.

Finally, electronic fire-control gear generally applies to anything that employs vacuum tubes. You'll encounter many vacuum tube amplifiers—some to drive small electric follow-up motors, others that control such devices as the amplidyne generator, others that couple electrical computing units in antiaircraft directors, and still others in radar circuits. The basic material on electronics will be covered in *Basic Electronics*, NavPers 10087, but you'll learn a lot more about this subject later on when you study the course for *Fire Control Technician* 2.

QUIZ

Select from the answers listed (a, b, c, or d) the one which BEST completes the statement or answers the questions in the following.

1. Which of the following effects is NOT corrected for when laying the gun?
   - a. Gravity on the projectile in flight
   - b. Drift
   - c. Distance to the horizon
   - d. Wind, air resistance, and powder temperature
2. Where in a main-battery or dual-purpose system on a ship is the computer located?
   - a. In the plotting room
   - b. On the main deck
   - c. Near the director
   - d. On the superstructure
3. Where in a main-battery or dual-purpose system on a ship is the director mounted?
   - a. On a high point above deck
   - b. Next to the plotting room
   - c. Below deck
   - d. Within walking distance of the guns
4. Which of the following is NOT measured by the director?
   - a. Range
   - b. Relative target bearing
   - c. Elevation
   - d. Relative motion
5. The director feeds information on present target to the
   - a. stable element
   - b. guns
   - c. rangefinder
   - d. computer
6. The computer output is fed continuously to the
   - a. fire-control tower
   - b. gun
   - c. director
   - d. rangefinder

7. The line of sight is established by
   a. the director
   b. the computer
   c. the stable element
   d. all three of the above
8. Present-target position is determined by
   a. range
   b. relative target bearing
   c. elevation
   d. all three of the above
9. Own ship course and speed are taken from the
   a. stable element
   b. director
   c. ship's compass and pitometer log
   d. computer
10. The stable element makes corrections for
   a. roll and pitch of ship
   b. range
   c. relative target bearing
   d. elevation
11. Which of the following factors does NOT enter the ballistic computation for own ship and target motion?
   a. Own ship course and speed
   b. Target course and speed
   c. Sight angle and deflection
   d. Corrections for roll and pitch
12. Sight angle pertains to
   a. range
   b. bearing
   c. elevation
   d. deflection
13. Sight deflection pertains to
   a. range
   b. bearing
   c. elevation
   d. time of flight
14. What is added to the target bearing and elevation angles to obtain the gun orders?
   a. Time of flight
   b. Wind angle and speed
   c. Gun train position
   d. Sight angle and sight deflection

CHAPTER 3

MECHANICAL COMPONENTS

SHAFTS, BEARINGS, AND HANGERS

The first things you see when you look inside a computer are many shafts and gears. And they're all there for specific purposes: to couple computing devices, to connect computing units, to drive and to position the dials. Equally important, external shafts and gears connect fire-control instruments—as the stable element with the computer, the director with its rangefinder, and the gun with its sights.

Small electric follow-up motors transmit motion to the various computing devices through shafts. You'll find that a computer contains several of these motors. However, a single motor may position several devices at different places in the machine.

Also, the positions of the shafts that couple these computing devices represent actual quantities—degrees of an angle or yards in distance. That fact makes accuracy of prime importance, and friction between moving parts must be held to a minimum. Shafts are therefore mounted in bearings and carefully machined parts.

Figure 3–1 shows a typical shaft assembly. The MOUNTING PLATE is used to support the whole assembly inside the equipment, and the HANGERS are used to support individual shafts. Then the ball bearings on the shaft are mounted in the hanger supports.

You can get a closeup picture of these ball bearings and hangers in figure 3–2. The ball bearing in figure 3–2A is constructed of three main parts—the outer race, inner race, and balls.

The outer race fits snugly into the hanger and supports the shaft and bearing assembly. The inner race fastens directly on the shaft. Then the balls are arranged to roll

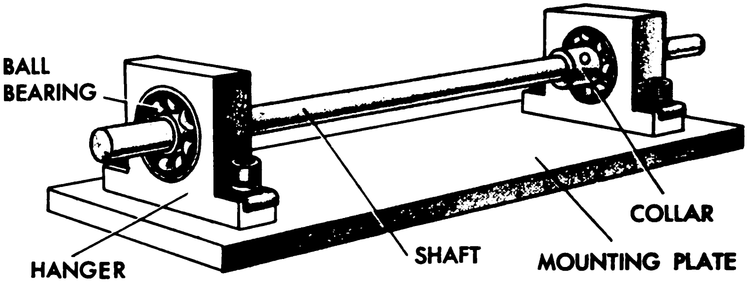


Figure 3–1.—Shaft assembly.

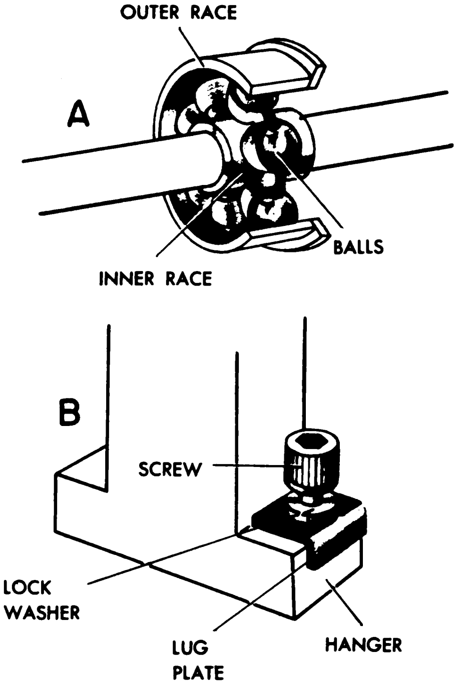


Figure 3–2.—Ball bearing and hanger.

freely on the outer and inner race surfaces as the inner race turns with the shaft.

In figure 3–2B you can see how the hanger is secured to the mounting plate. The hanger is held in place by machine screws. Notice that the screw is tightened down on a lock washer and lug plate. The lug plate prevents the lock washer from digging into the hanger, and at the same time increases the holding surface of the screw. The machine screw is of the allenhead type, and it takes an allen wrench to screw it in or out.

COUPLING DEVICES

Three principal devices are used to couple shafts end-to-end. These are the sleeve coupling, the Oldham coupling, and the universal joint.

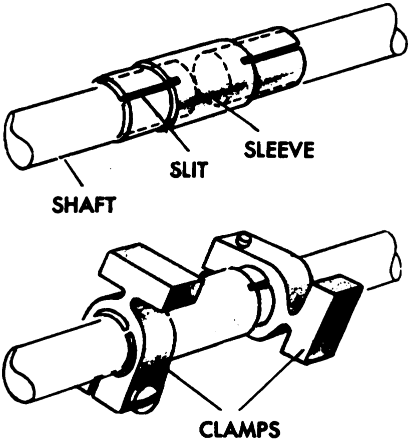


Figure 3–3.—Sleeve coupling.

Figure 3–3 shows you the sleeve coupling. It is used to join two shafts that lie in the same straight line; that is, shafts that are very closely alined. It consists of a simple metal tube or sleeve, slit at each end. The slitted ends enable the clamps to fasten the sleeve securely to the shaft ends. When the clamps are tight, the shafts are held firmly together and turn as one shaft.

One more thing is shown in figure 3–3. Take another look at those clamps and notice that they are a special sleevelike device with accommodations for tightening with a setscrew. The weight at the rear of the clamp merely offsets the weight of the screw and the overhang on the screw side. That makes an even distribution of weight, and shaft vibration is reduced.

The Oldham coupling, named for its inventor, is used to eliminate the need for perfect alinement between the shafts. At the same time it affords a convenient means to decouple the shafts quickly. You can see this coupling in figure 3–4.

The Oldham coupling has another use. As you know, metals expand and contract with changes in temperature. With long shafts this effect would be enough to cause trouble. Thus, this type of coupling compensates for this as the coil spring absorbs the changes in shaft lengths.

A study of figure 3–4 will show you all you need to know about the Oldham coupling. The lower drawing shows the

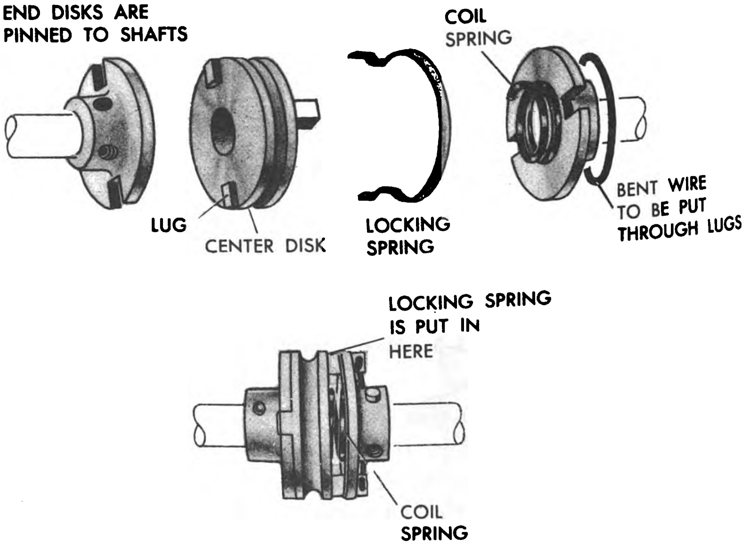

END DISKS ARE PINNED TO SHAFTS
COIL SPRING
LUG
CENTER DISK
LOCKING SPRING
BENT WIRE TO BE PUT THROUGH LUGS
LOCKING SPRING IS PUT IN HERE
COIL SPRING

Figure 3–4.—Oldham coupling.

coupling assembled without the locking spring. To insert this locking spring, simply put it around the coil spring between the center disc and right-hand end disc. Then hook it under the lugs of the center disc. The bent wire is put through the lug holes to provide a stop so that the shafts won't decouple when subjected to gunfire or other shock.

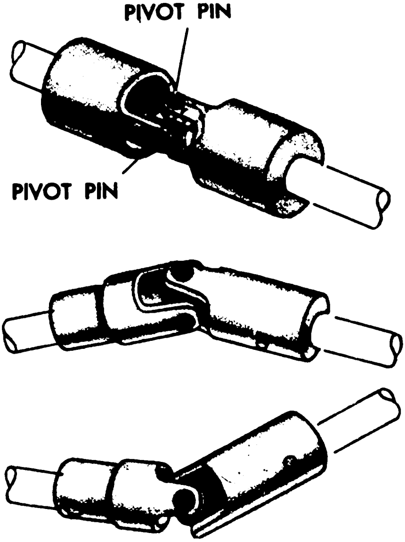


Figure 3–5.—Universal joint.

The UNIVERSAL JOINT is used to connect shafts that lie at an angle to each other. Figure 3–5 shows you this joint. Notice that the two pivot pins in this joint are coupled to a centerpiece, at right angles to each other. This makes it possible to bend the shafts, one with respect to the other, in any direction. Also, one shaft can drive the other even though the angle between the two is as large as 25° from alinement.

GEARS

When two shafts are not lying in the same straight line, but are parallel, motion can be transmitted from one to the

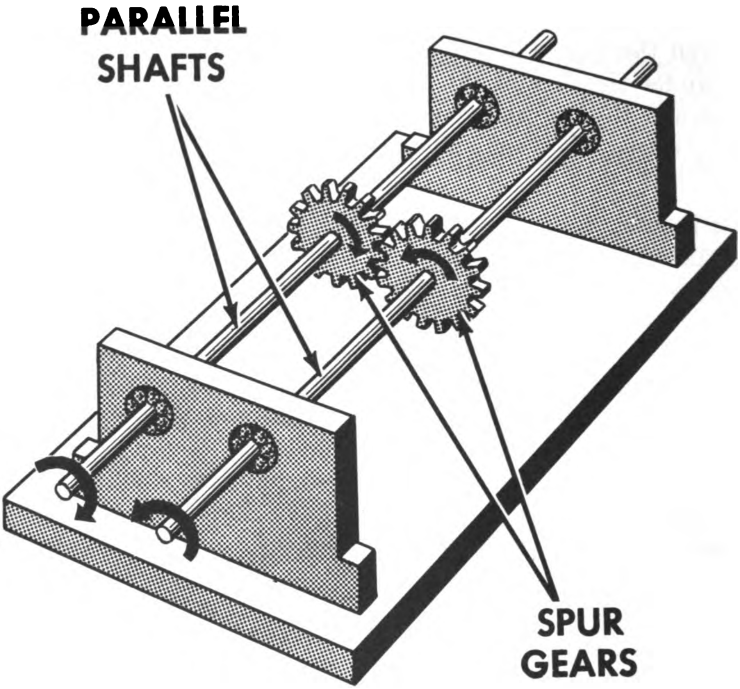


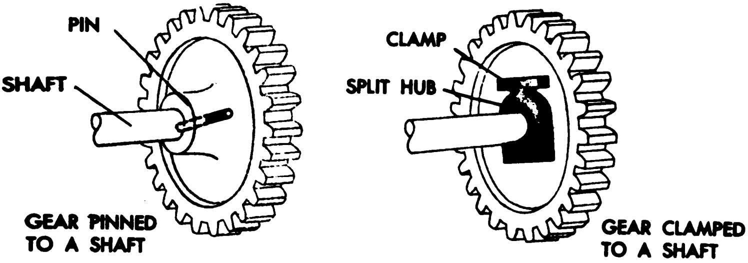
Figure 3–6.—Coupling parallel shafts.

other by means of SPUR GEARS. This setup is shown in figure 3–6.

Spur gears are wheels with mating teeth cut in their surfaces so that one can turn the other without slippage. When the mating teeth are cut so that they are parallel to the axis of rotation, as shown in figure 3–6, the gears are called STRAIGHT SPUR GEARS.

Spur gears are fastened to shafts in two principal ways: one by a pin through the shaft and gear hub, and the other by a clamp tightened on the gear hub. The gear hub, in the latter case, is slit like the sleeve coupling. Figure 3–7 shows you both fastening methods.

You will see the clamp method used more often because it furnishes a convenient means for adjustments. To make



GEAR PINNED TO A SHAFT

GEAR CLAMPED TO A SHAFT

Figure 3–7.—Fastening methods.

adjustments, simply loosen the clamp and slip the gear backward or forward on the shaft.

THE SHOCK ABSORBER

The shock absorber used in a computer is really just a special type of coupling. It has provisions for absorbing

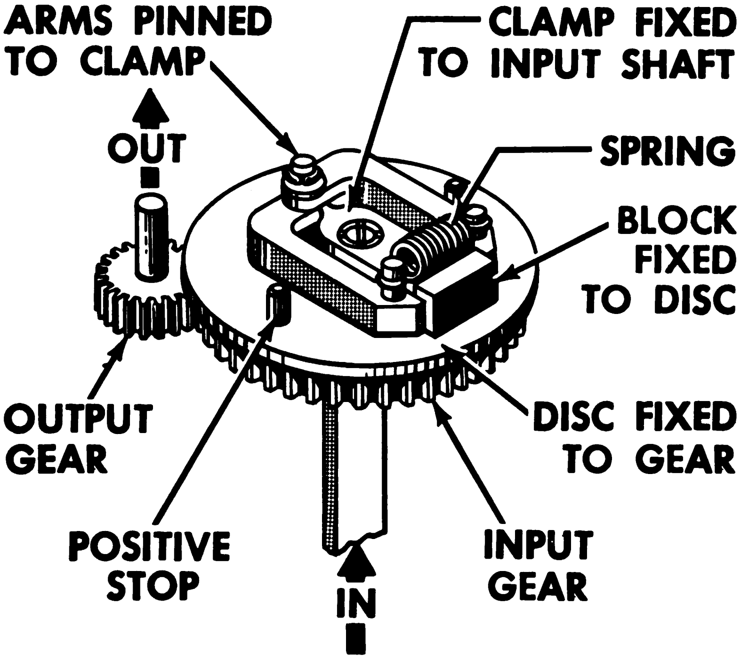


Figure 3–8.—Shock absorber.

shock which distinguish it from other couplings. Briefly, it consists of a clamp coupled to a gear by a spring and arm arrangement. The clamp fastens the shaft to the hub of the gear. You can see this setup in figure 3–8.

Follow the action in figure 3–8. To start with, the input shaft turns the input-gear hub clamp. The arm ends push the block, which is fixed to the disc that is fixed to the input gear. In turn, the input gear drives the output gear and output shaft. The thing to visualize is that the arms give against the spring to absorb the shock when the input shaft is started suddenly. That's the trick to the whole works.

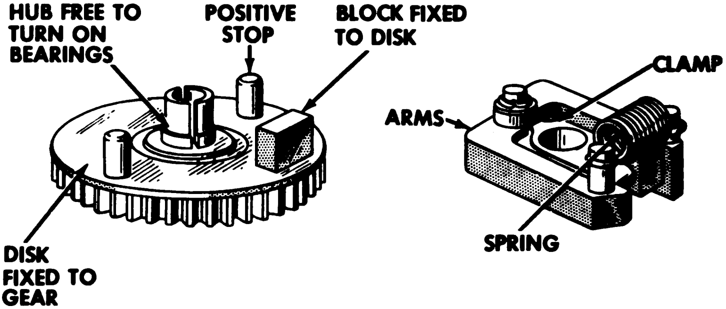


Figure 3–9.—Shock absorber, disassembled view.

Take a look at the disassembled view of the shock absorber in figure 3–9. It shows you exactly how it is constructed. There are two important things to see in the figure. First, note that the hub is FREE TO ROTATE in the gear and is mounted on ball bearings. And second, note that the clamp fastens the hub to the input shaft. Then, when the clamp is attached to the hub, the arms are stretched against the spring to sandwich the block on the disc. The two positive stops simply stop the arms to keep the spring from overstretching.

You'll find this shock absorber used in several places, but the most common use is in the intermittent drive—every one of which has a shock absorber. The intermittent drive will be discussed in the next chapter.

The two mating spur gears like those shown in figure 3–10A are called the DRIVER GEAR (fixed to the input shaft) and the DRIVEN GEAR (fixed to the output shaft). When two gears are mated like this, the driven gear is always rotated in the opposite direction to that of the driver gear. A study of the diagram will show you why.

When it is desired to have the driven gear turn in the same direction as the driver, an IDLER GEAR is used. Its only function is to REVERSE the driven gear rotation. You can study the action of the idler gear in figure 3–10B.

The next important thing to consider about gear trains is GEAR RATIO. When the driver gear and driven gear rotate at the same speed, their gear ratio is 1 to 1 (usually written 1:1). But if the driven gear rotates at one-half the speed of the driver gear, the ratio of the driver to the driven gear becomes 2:1. Conversely, if the driven gear rotates at twice the driver speed, the ratio of driver to driven becomes 1:2.

Now consider how to calculate gear ratios. Forget about the teeth and consider just two rubber-tire discs with equal diameters. If no slippage occurs, a half turn of the driver disc will produce a half turn of the driven disc because their circumferences are equal.

You will remember that the circumference of a circle is π times its diameter. Therefore, the disc speed ratios can be expressed mathematically by

$$\text{Ratio } \frac{C1}{C2}=\frac{\pi d1}{\pi d2}=\frac{d1}{d2}$$

where, $C1$ = circumference of disc 1
$C2$ = circumference of disc 2
$d1$ = diameter of disc 1
$d2$ = diameter of disc 2.

You can get the picture in figure 3–11 which shows that the speeds of rotation will be proportional (inversely) to the diameters—that is, the smaller the diameter, the greater the speed of rotation.

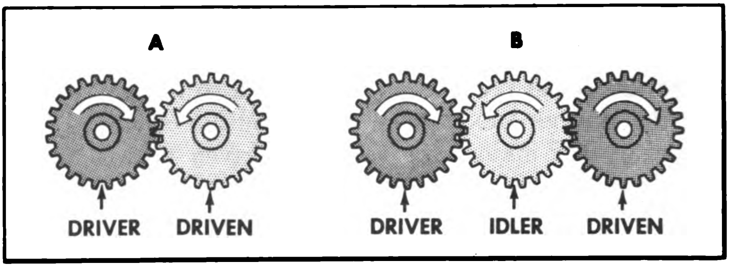


Figure 3–10.—Gear train.

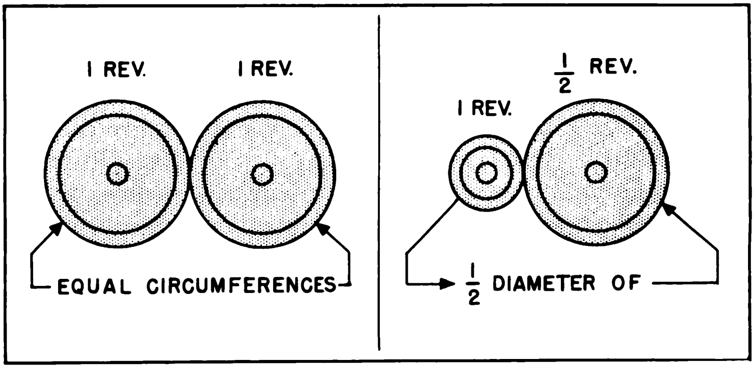


Figure 3–11.—Disc ratios.

Getting back to gears, it's easy to see that two mating spur gears of the same diameter must have the same number of teeth in order to mesh properly. Meshing means the engagement of two gears with teeth that match exactly.

Conversely, two gears of different diameters must have an UNEQUAL NUMBER OF TEETH in order to mesh . . . because the teeth must be of the same size to mesh, and obviously there's not enough room for the same number of teeth on the smaller gear.

To put it simply, gear ratios can be calculated by counting teeth. Actually, it's the most commonly used method among Fire Control Technicians.

Figure 3–12A illustrates two mating spur gears, one being one-half the diameter of the other, and one having 24 teeth and the other 12 teeth. Yes—just as you have figured—the ratio is 2:1. Now figure out exactly why.

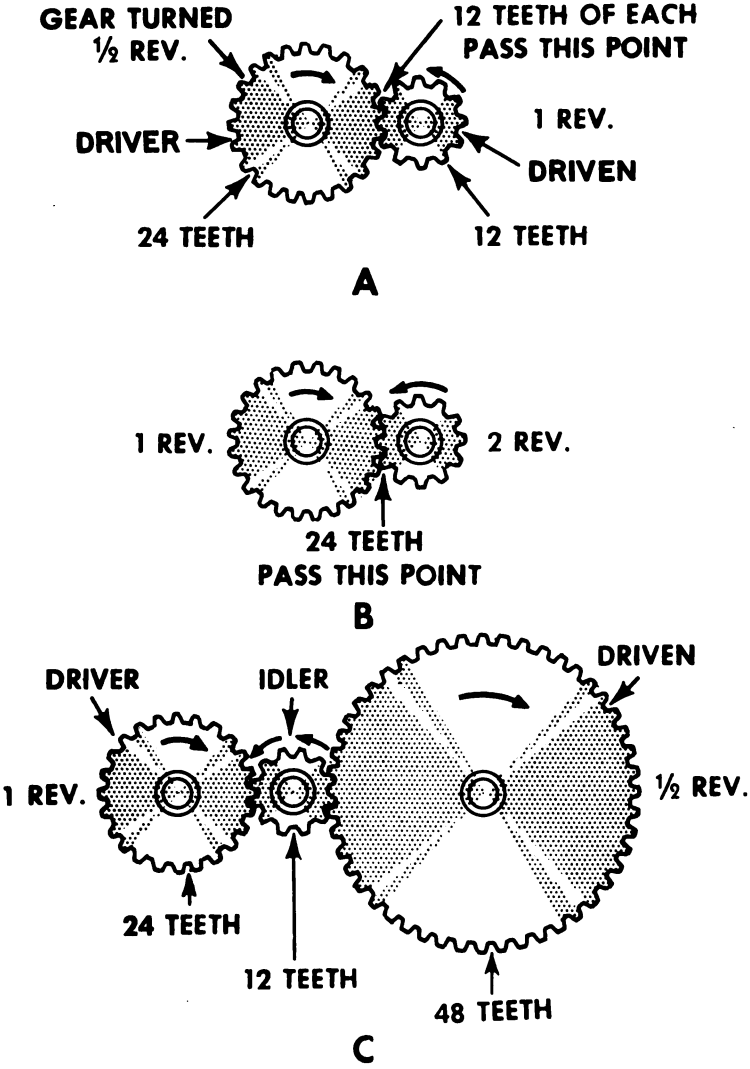
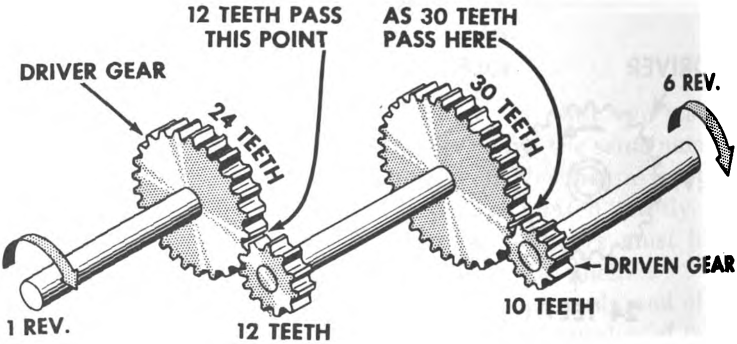


Figure 3–12.—Gear ratios.

It's easy to see that for each tooth of the driver that's turned past the point of mesh, there'll be one tooth of the driven gear turned past the same point. Consequently, if 12 teeth of the driver are turned, then 12 teeth of the driven gear have also turned. In other words, the driver has turned one-half revolution because it has 24 teeth, and the driven gear has turned one whole revolution as it has only 12 teeth. That means the speed ratio of the driver to the driven gear is 1:2. Consequently, the distance ratio of these same two gears is 2:1. A study of figure 3–12A and B will help make this clear to you.

As has been stated, to get the same direction of rotation for both driver and driven gears an idler gear is used. Now let's see what happens when the idler gear is placed between the two gears as in figure 3–12C. You can see that for each tooth of the driver that passes the mesh point, one tooth of the idler also passes. And for each tooth of the idler that passes the mesh point, one at the driven gear turns past that point also. So for one revolution of the driver gear, the idler makes 2 revolutions in the opposite direction, and the driven gear makes ½ revolution in the same direction as the driver.



$$\frac{24}{12} \times \frac{30}{10} = \frac{6}{1}$$

Figure 3–13.—Step up gear train.

Here's something a little different. Take a combination like that in figure 3–13 and you'll see a simple way to step up the speed of the output shaft six times. One way would be to use a 60-tooth gear to drive the 10-tooth output gear. But think of the size of the driver gear—it would be nearly THREE times as large in diameter as the 24-tooth driver gear in figure 3–13, and would be SIX times the diameter of the 10-toothed driven gear. The setup in figure 3–13 accomplishes this by fitting a small gear at one end of a shaft and a large gear at the other, and stepping up the speed in two stages. The driver gear turns the first small gear (ratio 2:1). And the large gear on that shaft, turning at the same speed as the small gear, turns the driven gear (ratio 3:1). The combined ratio $\frac{2}{1}\times\frac{3}{1}$ gives a stepped-up speed of 6:1.

Go ahead and study through figure 3–13; it'll do you good. And remember—the 12-tooth and 30-tooth gears rotate at the same speed.

SOME TYPES OF GEARS

You learned about straight spur gears back in the last section. They're the most commonly used type, but quite

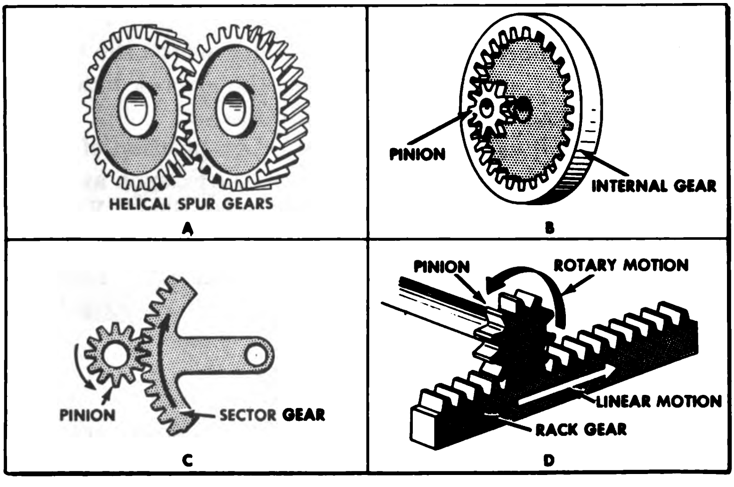


Figure 3–14.—Gear types.

often you'll run across another type of spur gear called the HELICAL spur gear.

In helical gears the teeth are cut slantwise across the working face of the gear. One end of the tooth, therefore, lies ahead of the other. In other words, each tooth has a leading end and a trailing end. A look at these gears in figure 3–14A will show you how they're constructed.

In the straight spur gears the whole width of the teeth comes in contact at the same time. But with helical (spiral) gears contact between two teeth starts first at the leading ends and moves progressively across the gear faces until the trailing ends are in contact. This kind of meshing action keeps the gears in constant contact with one another. Therefore, less lost motion and smoother, quieter action is possible.

Figure 3–14 also shows you three other gear arrangements in common use.

The INTERNAL GEAR in figure 3–14B has teeth on the inside of a ring, pointing inward toward the axis of rotation. An internal gear is always meshed with an external gear, or pinion, whose center is offset from the center of the internal gear. Either the internal or pinion gear can be the driver gear, and the gear ratio is calculated the same as for other gears—by counting teeth.

Often only a portion of a gear is needed where the motion of the pinion is limited. In this case the SECTOR GEAR (fig. 3–14C) is used to save space and material.

In fire control, values are transmitted by position of shafts or parts of mechanisms. Some of these parts, such as racks, move in a LINEAR rather than a rotary motion. You will often see a rack like that in figure 3–14D. Racks are simply straight bars on which gear teeth have been cut. They are employed in such devices as component and vector solvers.

THE BEVEL GEAR

So far most of the gears you've learned about transmit motion between parallel shafts. But when shafts are not parallel (at an angle), another type of gear is used—the

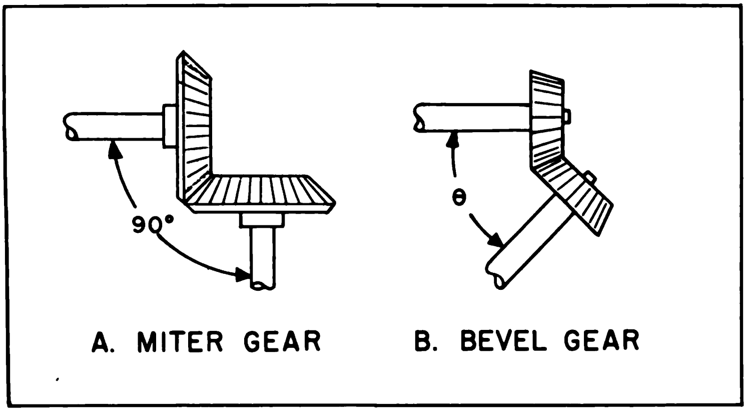


Figure 3–15.—Bevel gears.

BEVEL GEAR. This type of gear can connect shafts lying at any given angle because they can be beveled to suit the angle.

Figure 3–15A shows a special case of the bevel gear—the MITER GEAR. A pair of miter gears is used to connect shafts having a 90° angle, which means the gear faces are beveled at a 45° angle.

You can see in figure 3–15B how bevel gears are designed to join shafts at any angle. Gears cut at any angle other than 45° are called just plain bevel gears.

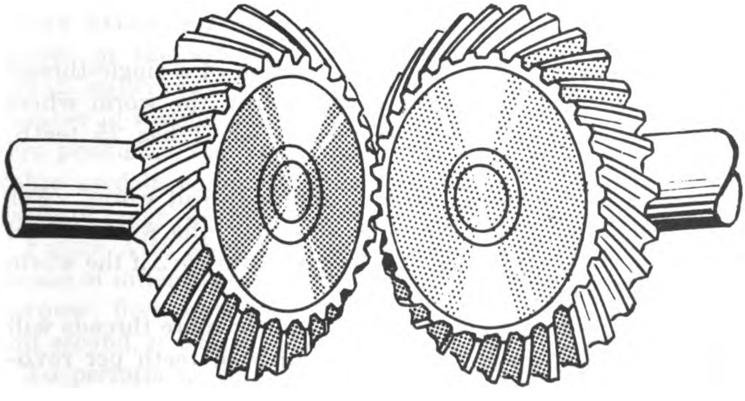


Figure 3–16.—Spiral bevel gears.

The gears shown in figure 3–15 are called STRAIGHT bevel gears, because the whole width of each tooth comes in contact with the mating tooth at the same time. However, you'll also run across SPIRAL bevel gears with teeth cut so as to have advanced and trailing ends. Figure 3–16 shows you what spiral bevel gears look like. They have the same advantages as other spiral (helical) gears—less lost motion and smoother, quieter operation.

THE WORM AND WORM WHEEL

Worm and worm-wheel combinations, like those in figure 3–17, have many uses and advantages. But it's better to understand their operating theory before learning of their uses and advantages.

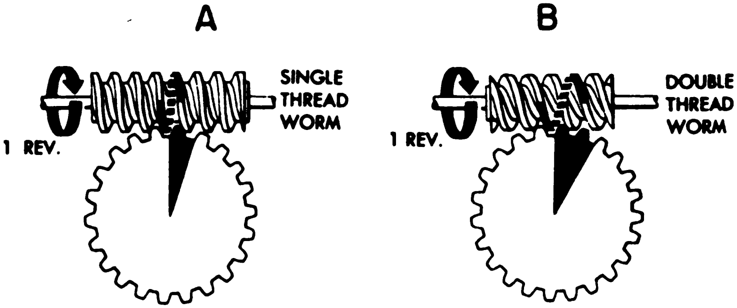


Figure 3–17.—Worm gears.

Part A of figure 3–17 shows the action of a single-thread worm. For each revolution of the worm, the worm wheel turns one tooth. Thus if the worm wheel has 25 teeth, the gear ratio is 25:1.

Part B of the figure shows a double-thread worm. For each revolution of the worm in this case, the worm wheel turns two teeth. That makes the gear ratio 25:2 if the worm wheel has 25 teeth.

Likewise, worms having three or four or more threads will turn the worm wheel the same number of teeth per revolution as there are worm threads.

The worm and worm wheel setup has two chief advantages which determine its use. First, it has large gear ratios which can produce large speed reductions. This permits a small electric motor to drive a large load. The work done is the same, but the rate of doing the work is reduced. And second, it's usually not reversible; that is, the worm can drive the worm wheel, but the worm wheel cannot drive the worm. This is especially advantageous where two electric motors in a computer are driving two different quantities into one line through a differential. It prevents one quantity from backing up into the other. The backing-up action would cause the output to be in error. There are a few unusual cases where the worm has several threads, and the slantwise pitch of the worm wheel teeth is great enough so that the worm wheel can actually drive the worm, but these are exceptions.

THE VEEDER COUNTER

When making adjustments in rangekeepers and computers, it is necessary to count shaft revolutions. This is done with the Veeder counter.

No doubt you've seen counters used in automobiles to indicate mileage. Well, the Veeder counter used in fire-control works on the same principle. But instead of indicating mileage, it counts the revolutions of a shaft value.

The following definition will help you visualize this: The SHAFT VALUE is the value that a shaft carries in one revolution, or the value per revolution. It follows that the TOTAL SHAFT VALUE is the shaft value multiplied by the number of revolutions the shaft is positioned away from its zero position. The value that a shaft carries might be any value used in computing the fire-control problem, such as yards of range, degrees of bearing, or target speed in knots.

Figure 3–18 shows a counter connected to a shaft by means of miter gears. In this case the counter serves a dual purpose: first, it is used for indicating proper adjustment; and second, it indicates revolutions of shaft value.

To perform an adjustment on the setup shown in figure 3–18, first set the computing device at its zero position. Then

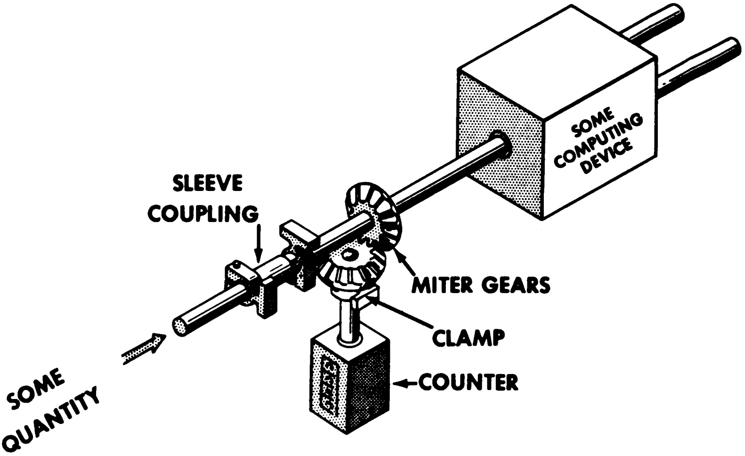


Figure 3–18.—Veeder counter.

loosen the clamp at the counter and turn the counter until it, too, reads zero, and tighten the clamp. Now both the computing device and the counter area are at their zero positions.

Next, loosen the clamp at one end of the sleeve coupling and turn the input quantity until it and the counter are on zero at the same time. Finally, tighten the clamp of the sleeve coupling to complete the adjustment.

This type of counter is called an off-line counter, as it can be disconnected without affecting the adjustment.

HAND CRANKS

Not all inputs to a computer or rangekeeper are automatic. For instance, all the wind values are cranked in by hand. Also, INITIAL ESTIMATES of such quantities as range, target course, and target speed are cranked in by hand to expedite the solution. In fact, some rangekeepers solve the whole fire-control problem from inputs cranked in manually. In turn, corrections to these input quantities are cranked in from time to time as the problem progresses.

There are several types of hand cranks—some simple and some complex. The simple ones are merely used to crank in a quantity, whereas the more complex hand cranks may have holding frictions, a selector switch, or a locking device built in to serve several other purposes. But regardless of how many accessories the crank may have, it's still the simple crank built up.

The most simple crank consists of a shaft with a knob pinned to one end and a gear pinned to the other. Then a housing-like adapter is fitted around the shaft with some way of securing the whole assembly to a side or top of the computer.

In order to get a picture of the simple crank built up, look at figure 3–19. This crank has features in common with the several types of cranks you'll be working with. Take the four main features, one at a time, and study them.

First, the crank has a HOLDING FRICTION created by the pressure exerted against two cork discs by a collar, a bushing, and a metal disc. You can locate these parts in the upper part of the drawing in figure 3–19. Notice that the coil spring furnishes the pressure. These holding frictions keep the hand crank positioned, and more important, serve to prevent motion from backing out through the hand crank.

Second, consider the FRICTION RELIEF DRIVE. The drive gear is held to the shaft by the friction relief drive consisting of a flat spring, a wooden washer, and a clamp. If the line hits the end of a limit stop, or if the torque on the line is too great because of some maladjustment, the friction will slip so that the mechanisms and gears within the machine will not be damaged. You can see these parts at the lower end of the crank.

The third feature is the PLUNGER for changing the position of the shaft. The crank in figure 3–19 has two positions—the IN-POSITION and the OUT-POSITION. In changing position, the shaft and drive gear move in relation to the adapter housing. The plunger is used to hold the shaft and knob in either of these two positions. The plunger is pulled out and the crank is pushed or pulled to its new position. Then the plunger is returned by its spring when released.

Now get these in- and out-positions straight. Actually, this crank is built to take the place of TWO simple cranks

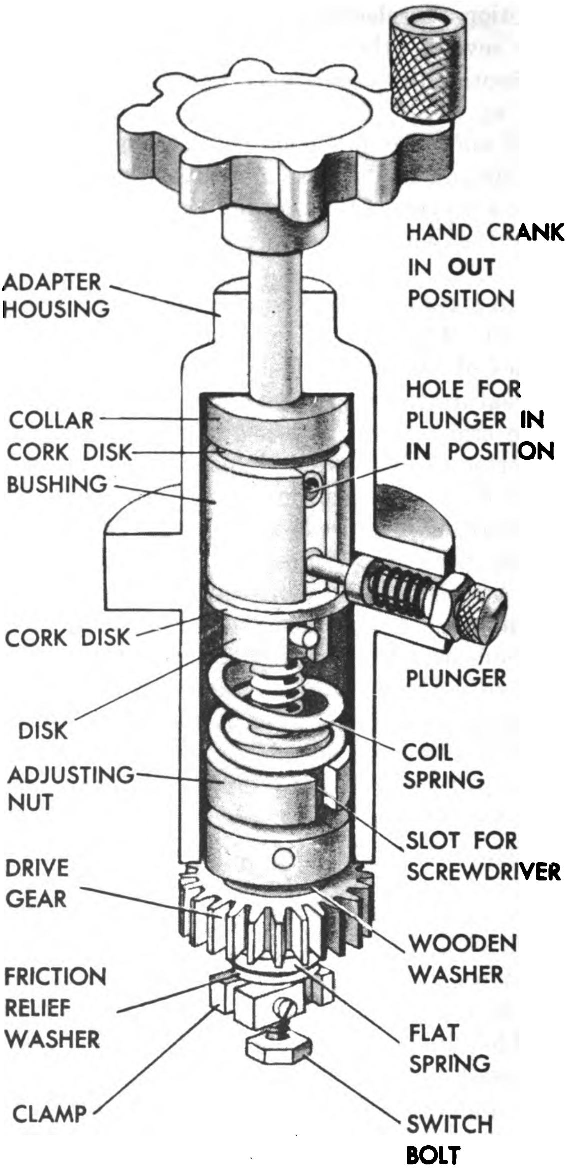


Figure 3–19.—Hand crank.

(fig. 3–20). In the in-position, the drive gear is meshed with one gear to crank in a certain quantity; and in the out-position, the drive gear is meshed with another gear to crank in a distinctly different quantity.

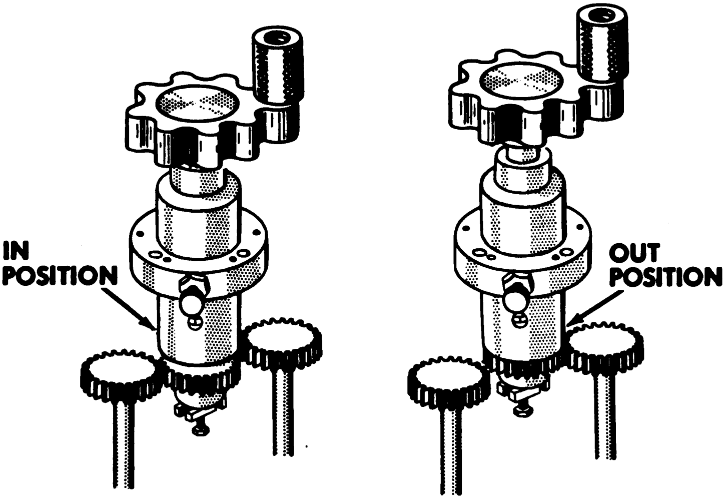


Figure 3–20.—In- and out-positions of a hand crank.

The fourth feature is the ADJUSTABLE SWITCH BOLT. This bolt is used to open and close a switch, usually to control an electric motor. It is adjusted to operate the switch at exactly the right time, when the knob is changed from one position to the other.

If you know the crank assembly in figure 3–19, you'll have no trouble with cranks. Remember that the crank can be used to crank in two quantities (one for each position), and it can operate a switch.

Don't underestimate the importance of these basic mechanical units. Although they may seem simple, they're subject to wear and tear. That means you'll be replacing them from time to time, or filing off burred edges, or just cleaning and lubricating their working parts. These basic units are used in the assembly of complex fire-control computing mechanisms, which you'll learn about in the next chapter. For more information on basic mechanical units, consult *Basic Fire Control Mechanisms*, OP 1140.

QUIZ

Select from the answers (a, b, c, or d) listed the one which BEST completes the statement or answers the question.

1. Which of the following is NOT a purpose of shafts and gears?
   a. To couple computing devices
   b. To position dials
   c. To step up power
   d. To connect computing units to their drives
2. Which part of a ball bearing assembly fastens directly to the shaft?
   a. Outer race
   b. Hanger
   c. Inner race
   d. Mounting plate
3. Shafts are mounted in
   a. rubber
   b. bearings
   c. couplings
   d. shock absorbers
4. The sleeve coupling is used to
   a. join shafts that lie in the same straight line
   b. eliminate the necessity for perfect alinement between shafts
   c. join shafts that lie at an angle to each other
   d. compensate for metallic changes due to temperature
5. The sleeve coupling is slit at either end to
   a. allow for play in the coupling
   b. permit expansion and contraction in the shafts
   c. enable quick disassembly
   d. permit fastening the sleeve securely to both shafts with clamps
6. The Oldham coupling should be used when
   a. perfect alinement between shafts is necessary
   b. temperature changes cause changes in shaft lengths
   c. shafts lie at an angle to each other
   d. shafts lie in exactly the same straight line
7. A universal joint is used to connect shafts which
   a. lie at an angle to each other
   b. lie in the same straight line
   c. must be perfectly alined
   d. are parallel to each other

8. The clamps of the sleeve coupling are weighted at the rear to
    a. obtain perfect alinement
    b. reduce shaft vibration
    c. absorb changes in shaft length
    d. increase weight of coupling
9. Gears whose mating teeth are cut parallel to the axis of rotation are called
    a. sector gears
    b. spiral gears
    c. straight spur gears
    d. miter gears
10. When two shafts lie parallel to each other, motion may be transmitted from one to the other by means of
    a. an Oldham coupling
    b. a universal joint
    c. mating teeth
    d. spur gears
11. A shock absorber is a special type of
    a. cam
    b. couple
    c. gear
    d. compensator
12. In a pair of mating spur gears, the one fixed to the input shaft is called the
    a. idler gear
    b. driven gear
    c. driver gear
    d. straight spur gear
13. In a pair of mating spur gears, the one fixed to the output shaft is called the
    a. spiral gear
    b. driven gear
    c. driver gear
    d. helical gear
14. The direction of rotation of a driven gear can be reversed by
    a. a driver gear
    b. a shock absorber
    c. a spiral gear
    d. an idler gear
15. What is the speed ratio of the driven gear to the driver gear if the driver gear has 12 teeth, the idler gear 6 teeth, and the driven gear 36 teeth?
    a. 1:2
    b. 1:3
    c. 1:4
    d. Insufficient information given to solve

16. Another name for a helical gear is
    a. a spur gear
    b. a straight spur gear
    c. a spiral gear
    d. an idler gear

17. A sector gear is used to
    a. obtain smooth motion
    b. prevent lost motion
    c. save space and material
    d. obtain quieter action

18. A pair of miter gears is used to connect shafts at what angle?
    a. 45°
    b. 60°
    c. 90°
    d. 110°

19. What is the gear ratio of a single-thread worm and wheel with 24 teeth?
    a. 12:1
    b. 12:2
    c. 24:1
    d. 48:1

20. With which of the following can a small electric motor BEST drive a large load?
    a. Idler gear
    b. Oldham coupling
    c. Internal sector gear
    d. Worm and worm wheel

21. Which of the following CANNOT be done by the Veeder counter?
    a. Indicate proper adjustment
    b. Reduce error
    c. Count shaft revolutions
    d. Indicate shaft value

22. What feature of the hand crank keeps it positioned and prevents motion from backing out?
    a. Holding friction
    b. Friction relief drive
    c. Plunger
    d. Adjustable switch bolt

23. In order to shift the hand crank position you must release the
    a. switch bolt
    b. friction relief drive
    c. clamp
    d. plunger

24. A step-down gear train has four gears having 12, 24, 6, and 48 teeth respectively. How far will the 48-tooth gear turn per revolution of the 12-tooth gear?

a. 1/4 turn
b. 1/16 turn
c. 1/8 turn
d. 1/2 turn

CHAPTER 4

BASIC MECHANISMS

MECHANICAL DIFFERENTIAL

Now that you've looked over that computer or rangekeeper, you're probably wondering just how it works. And you'll be wondering a long time if you just watch that maze of gears and electrical units in operation.

It looks complicated, and it is complicated. But like any complex machine, it's made up of simple component mechanisms. The component mechanisms used in fire control are called STANDARD UNITS.

You'll have no trouble learning the function of each of the standard units. When you know them, you'll know the computer. Some of the simpler standard units will be discussed briefly in this chapter, but for detailed coverage of the primary units, you should study OP 1140, *Basic Fire Control Mechanisms*.

The mechanical differential is the most common standard unit you'll run across. You'll see it used in both electrical and mechanical computers. In one respect the differential is a computing device, because it can be used to ADD or SUBTRACT two quantities. That means it has two inputs and one output. The inputs are the two quantities to be subtracted or added, and the output is the difference or the sum of the two inputs.

Figure 4–1 shows one example of the use of a differential. The differential is represented in the figure by a circle with a cross in it. In this case the differential adds two angles—the director angle and the lead (or deflection) angle. They're the two inputs to the differential. Then the output angle of the differential is the algebraic sum of the two input angles,

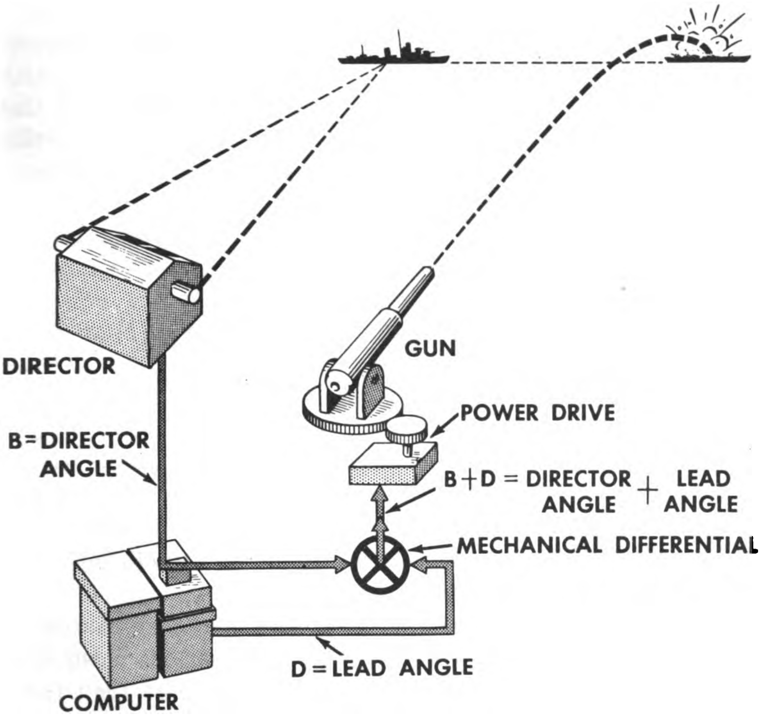


Figure 4-1.—Adding angles.

and it becomes the gun-train angle. The output of the differential, fed to the gun power-drive, positions the gun.

Don't get the idea the differential is an instrument separate from all others. Actually, the one shown in the figure is located inside the computer, and works in conjunction with many other units.

There are two types of differentials: the BEVEL-GEAR DIFFERENTIAL and the SPUR-GEAR DIFFERENTIAL. The spur-gear type is encountered only in special equipment and will not be discussed here. If you run across one, however, don't worry about it, because fundamentally it operates very much the same as the bevel-gear types which will be covered here.

Bevel-Gear Differential

You can see a cutaway drawing of the bevel-gear differential in figure 4–2. To see how it works, start by locating the SPIDER in the figure. The spider assembly consists of the spider shaft, the block, and the shaft at right angles to the spider shaft. The spider parts are all fixed to each other. The spider shaft supports the whole differential by the ball bearings at each end, and the ball bearings are mounted in hangers. Then the whole spider assembly is free to turn on its bearings.

Next, notice the INPUT GEARS. These gears are spur-gears which rotate about the spider shaft on another set of ball bearings. The two END GEARS are bevel gears, and are fixed to the sleeve ends supporting the input gears.

In operation, these end gears drive the SPIDER GEARS which also are bevel gears. Notice that the spider (or inner) gears "walk" around the end gear faces to turn the spider assembly and shaft. Then the rotation of the OUTPUT GEAR, fastened to the spider shaft, becomes the output.

More precisely, if either input gear is held stationary, while the other input gear is turning, the one that is turning will drive the spider gears. As the spider gears turn they roll on the stationary end gear surface (attached to the stationary input gear). This results in a rotary motion of the spider shaft.

Next, rotate each end gear at equal speeds—one clockwise, and the other counterclockwise—while looking at the right end of the spider shaft. See what happens. The right-end gear attempts to rotate the spider gears in one direction, while the left-end gear tends to rotate them in the other direction. The result is a zero rotation of the spider, and zero output. Mathematically, this is the same as subtracting two equal quantities.

Here's another example. Reverse the rotation of one end gear. Now if you look at one end of the spider shaft, you will see that the end gears are rotating in the same direction. If both end gears are rotating at the same speed in the same direction, the resultant spider rotation will be twice the speed

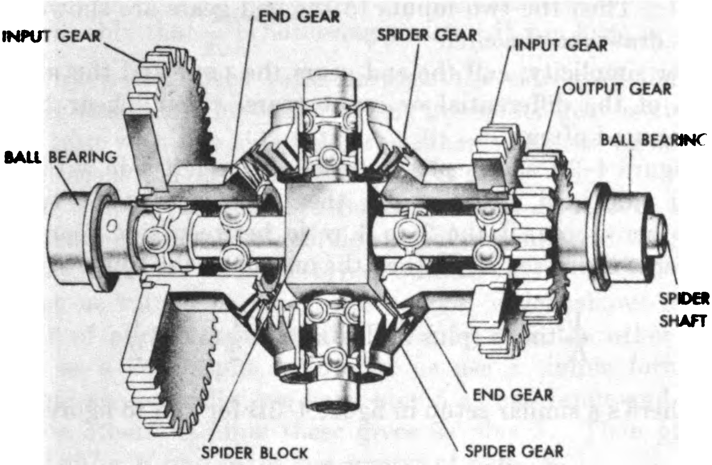


Figure 4–2.—Bevel-gear differential.

of either end gear. This is the same as adding two equal quantities.

Finally, suppose you hold the spider shaft and turn one end gear. What happens? A study of figure 4–2 will tell you that the other end gear turns an EQUAL amount in the OPPOSITE direction.

Gear Ratio

If you hold one end gear and turn the other in a certain direction, you'll see that the spider turns in the same direction, but only ONE-HALF as far. This means that the turn ratio between either end gear and the spider is 2 to 1. Actually the 2 to 1 ratio is seldom found in differential gearing in any computer for reasons of design, but for the sake of clarity, let us assume that all differentials have 2 to 1 gearing and that the final output is complete and correct.

Figure 4–3 shows six different examples of algebraic addition with a differential. A study of them will tell the story. But first, look at the symbol of the differential in A of the figure. The cross represents the spider, and the line drawn from the point of intersection represents the spider shaft. Then the two inputs to the end gears are shown by lines drawn to the circle.

For simplicity, call the end gears the LEFT and the RIGHT SIDE of the differential or input gears. You'll hear those terms used often.

Figure 4–3A shows plus 5 turns on the left side with the right side held. The spider then rotates plus 2½ turns. In other words, if the 2 to 1 ratio between side gear and spider is expressed as K, then the output at the spider equals

$$\frac{1}{K} \text{ times (plus 5 plus zero)} = \frac{1}{2}(5) = 2\frac{1}{2}.$$

There's a similar setup in figure 4–3B for you to figure out.

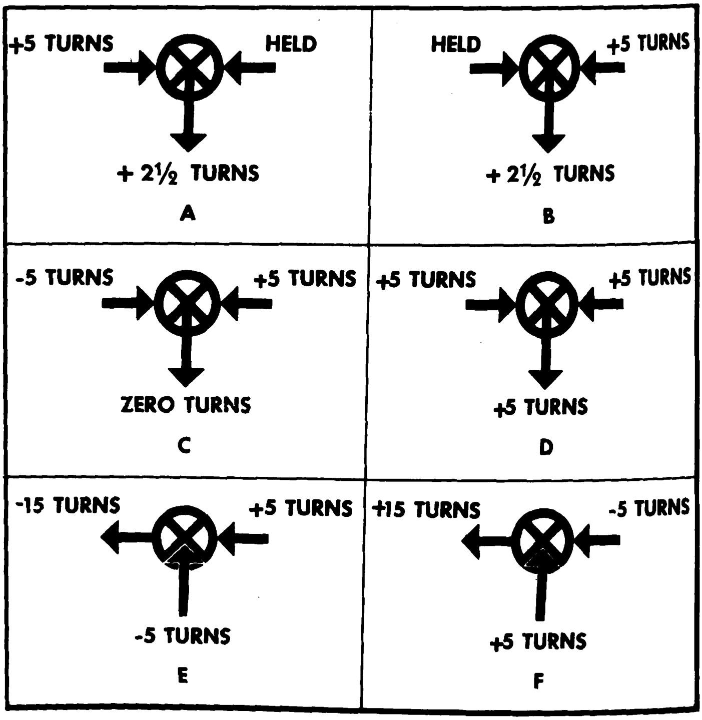


Figure 4–3.—Adding algebraically.

Probably that $\frac{1}{K}$ is bothering you, but if you keep in mind that K is the speed ratio between the side gear and the spider shaft, it'll be easy. When the spider gear is turned one turn with one side held, the other side gear turns two revolutions. Thus, the constant K is 2.

To simplify this always remember that K is 2 in these illustrations and the algebraic sum of the inputs divided by K, (2), will give you the correct output.

Let us return to figure 4–3A again which shows us an input of plus 5 turns on the left side with the other side held or a zero input. Now let us use a simple formula; adding algebraically, we have plus 5 as one input and zero as the other. Adding these gives us plus 5. Then plus 5 divided by K or 2 gives our answer of plus 2½.

In figure 4–3C the inputs are minus 5 on the left side and plus 5 on the right side. The output is zero because the side gear motion cancels out at the spider gear, but let us check this with our formula. We have a minus 5 as one input and a plus 5 as the other input and we divide this by K. Once again we will substitute 2 in place of K—so we get $\frac{5-5}{2}=0$.

Now let us look at figure 4–3D and again use our formula. We have an input of plus 5 on each side which gives us an input of plus 10 but now we divide this by our constant, 2, and our answer is plus 5.

Finally, look at something a little different in figure 4–3E. Here we have a plus 5 at one side and a minus 5 at the spider as our two inputs as indicated by the arrows. Will our formula work here? Not unless we change it a little. Why must we change it? Remember the gear ratio, that the spider only turns ½ revolution to a turn of the side gear so if we move the spider one revolution the side gear will make two revolutions. Keeping this in mind and that our constant K is 2, we can now reverse our procedure and come out with a new formula when the spider is used as one input. Now instead of dividing our side gear inputs by two, we will multiply our spider input by our constant and add this to our other input and come out with a correct answer. So let us apply our new formula to figure 4–3E and we have minus 5 on the spider times 2 and a plus 5 on the side gear. If we add this algebraically, we have a minus 15. Using the same formula for figure 4–3F, we have plus 5 turns of the spider multiplied by 2 or plus 10 which we add algebraically to our other input of minus 5 turns and our answer is plus 15.

The differential operation is extremely important, and you can thoroughly master it by working problems like the sample problems in the figure. Make up some problems of your own and try them. Then after you complete this chapter, work the differential problems in the quiz.

THE INTERMITTENT DRIVE

Many times you'll find mechanisms in a computer that operate only within certain limits—just as a gun can be elevated and depressed only within certain limits.

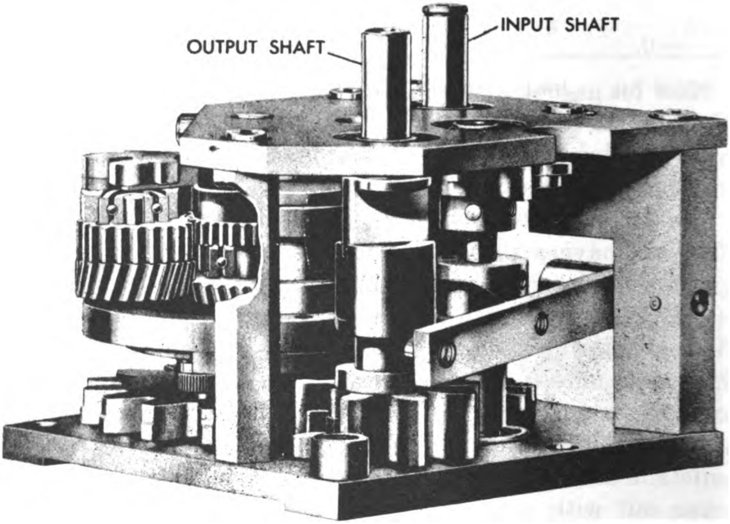


Figure 4–4.—Intermittent drive.

Often in a computer you will find several mechanisms with different limits of operation attached to the same line of gearing. For example, the present range line may turn from 0 to 35,000 yards, but a range cam connected to that line may be cut to take values of range from only 750 to 22,500 yards. (The range cam itself will be explained later in this chapter.) Where such range limits are imposed, a mechanism is needed that will disconnect the range input to the cam at the instant the input goes below 750 yards or above 22,500 yards. The mechanism that fills this need is the INTERMITTENT DRIVE. See figures 4–4 and 4–5.

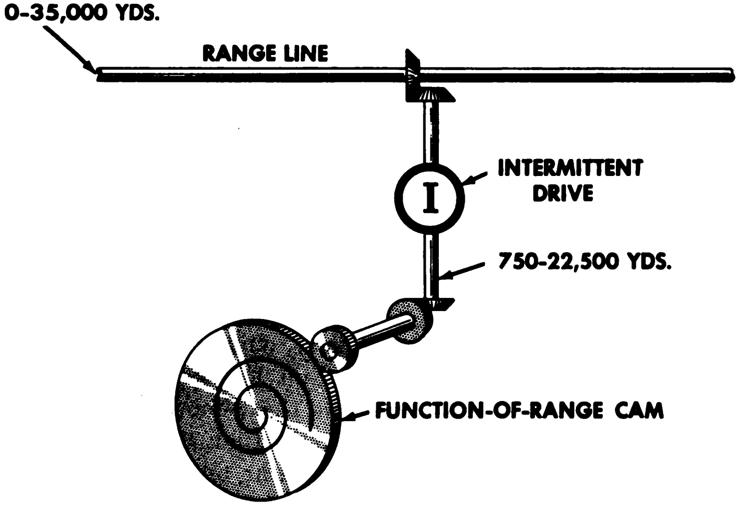


Figure 4–5.—One use for the intermittent drive.

In this example all values of range can turn the input to the intermittent drive, but only those values between 750 and 22,500 will be transmitted to the cam. When the input line turns above or below these limits, the output gear will lock and stay locked until the values coming into the intermittent drive are again within the limits which the cam can handle. Intermittent drives are used in this way to connect and disconnect a variety of mechanisms including multipliers, component solvers and transmitters.

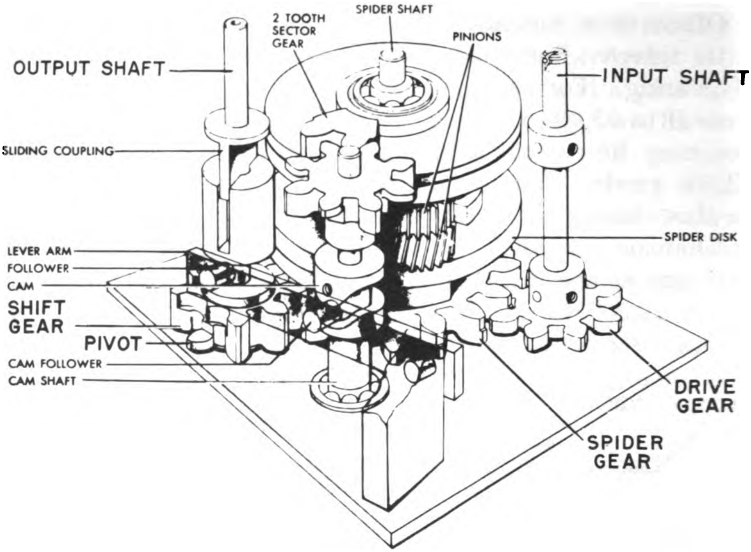


Figure 4–6.—Intermittent drive with the top plate off.

Figure 4–6 shows the intermittent drive with the top plate off. Notice that on the bottom plate there are three spur gears, the drive gear, the spider gear, and the shift gear. The drive gear drives the spider gear, which drives the shift gear. The discs and pinion gears on the spider shaft are there to reduce the speed, so that the 2-tooth sector gear on the top will drive much more slowly than the spider gear. The 2-tooth sector gear drives the gear on the cam shaft very slowly. The cam lifts the lever arm up and down. At the end of the lever arm there is a small follower which fits into the groove on the shift gear. As the lever arm moves upwards, it slides the shift gear up along the output shaft until it finally is out of mesh with the spider gear. That's how the intermittent "cuts out." The input can keep on turning after this, but the shift gear will not be meshed, and it will not turn.

Controlling the Cam

In the intermittent drive, the shift gear stays IN mesh for a certain number of revolutions of the drive gear and then moves up OUT of mesh. The number of revolutions the shift gear stays in mesh is controlled by the cam and gearing.

The cam in this case is really a collar with a detent in it. Look at figure 4–7 and locate this detent. The detent is low for ¼ of the distance around the collar, and, while the lever pin is in this low part, the shift gear meshes with the spider gear. When the follower is not in this low part of the detent, the lever arm slides the shift up its shaft out of mesh.

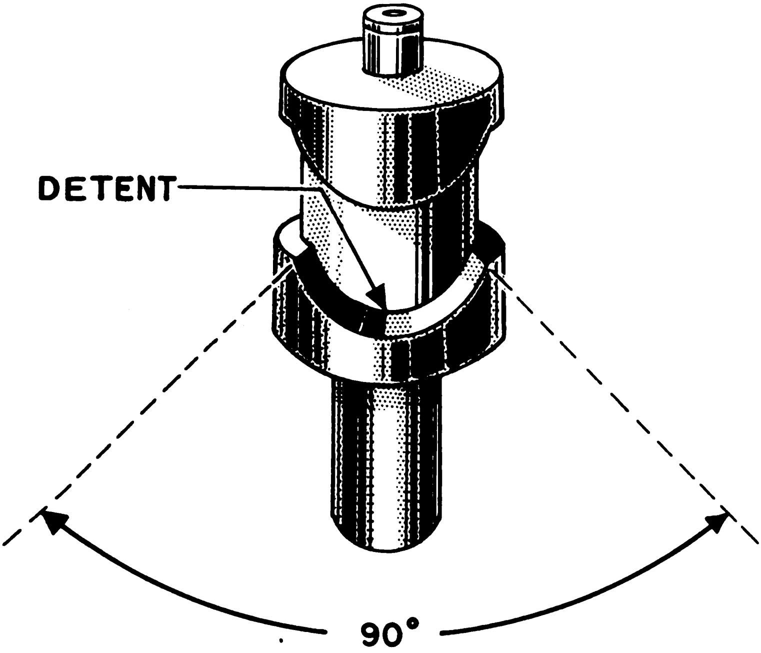


Figure 4–7.—Cam front view.

Figure 4–8 shows the cam-drive gearing. The gear on the top of the cam shaft has 8 teeth, so it will be turned ¼ revolution for each revolution of the 2-tooth sector gear which drives it. Since the shift gear is IN mesh for only ¼ turn of the cam shaft, the cam will hold the shift gear IN mesh for only ONE revolution of the 2-tooth sector gear. Obviously,

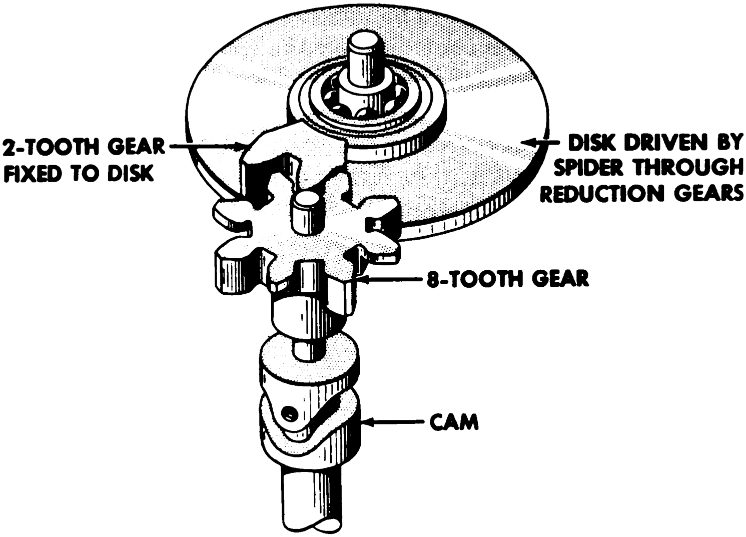

2-TOOTH GEAR FIXED TO DISK
DISK DRIVEN BY SPIDER THROUGH REDUCTION GEARS
8-TOOTH GEAR
CAM

Figure 4–8.—Cam-drive gearing.

since the shift gear must stay in mesh for many revolutions of the drive gear, there has to be a great reduction in speed between the revolutions of the input shaft and the revolutions of the 2-tooth sector gear. The PLANETARY GEARING above the spider gear takes care of this reduction. It gives a ratio of 1 to 29 so that the shift gear will stay meshed for 29 revolutions of the drive gear.

Planetary Gearing

Figure 4–9 shows you the arrangement of the planetary gearing. As the drive gear turns the spider gear, the two pinions of the planetary reduction gearing are carried around on the disc which is screwed to the spider gear.

While being carried around, the two pinion gears rotate on their own shaft. These pinions are fastened to each other. They mesh with the two inner gears on the stationary shaft, which are housed inside the casing between the discs. The two pinions have the same number of teeth, but the movable inner gear has two more teeth than the stationary inner gear. As the pinions are carried around, the lower one rolls on the stationary inner gear. Since the upper pinion is fixed to the low pinion it turns at the same rate as the lower one, and meshes with the movable inner gear. But, as the movable inner gear has the two extra teeth, it will be driven around only an amount equal to two of its teeth for each whole revolution of the spider gear. Accordingly, this movable inner gear turns very slowly. The disc carrying the 2-tooth sector gear is fastened to this movable inner gear. The 2-tooth sector gear will also turn very slowly compared to the spider gear. In fact, it turns once for 14½ revolutions of the spider gear, or for 29 revolutions of the input gear.

Summing up, the shift gear stays meshed for ¼ revolution of the cam. In turn, TWO revolutions of the disc and 2-tooth gear turn the cam ½ revolution (four teeth of the 8-tooth cam gear). See figure 4–9. Also, since the shift gear and spider gear remain meshed for 14½ revolutions of the spider, the cam turns ¼ revolution for every 14½ revolutions of the spider gear.

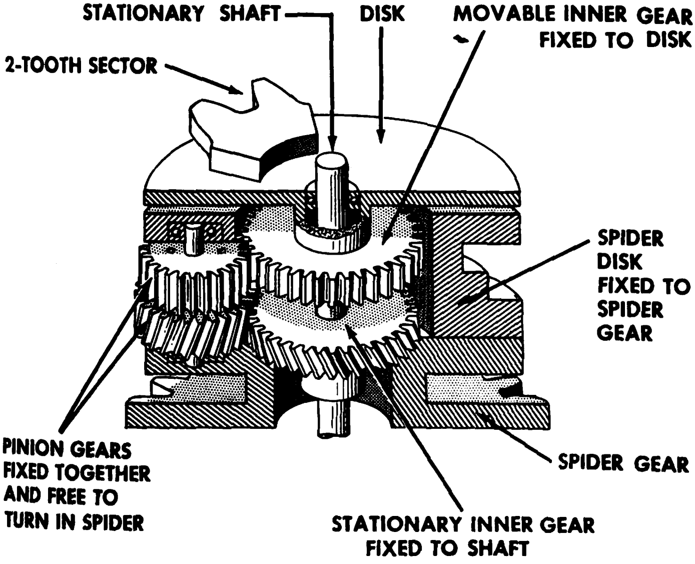

STATIONARY SHAFT
DISK
MOVABLE INNER GEAR FIXED TO DISK
2-TOOTH SECTOR
SPIDER DISK FIXED TO SPIDER GEAR
PINION GEARS FIXED TOGETHER AND FREE TO TURN IN SPIDER
SPIDER GEAR
STATIONARY INNER GEAR FIXED TO SHAFT

Figure 4–9.—Planetary gear arrangement.

It follows that the shift gear will stay meshed, and the output shaft will turn for 29 revolutions of the input shaft, because there's a 2 to 1 step-down ratio between the input gear and spider gear.

As the cam follower lowers into the detent the intermittent starts driving through. Then the spider gear drives two things—the cam, and the shift gear. After 14½ revolutions of the spider, the cam is turned ¼ revolution, and the follower lifts out of the cam's detent. Then the intermittent stops driving.

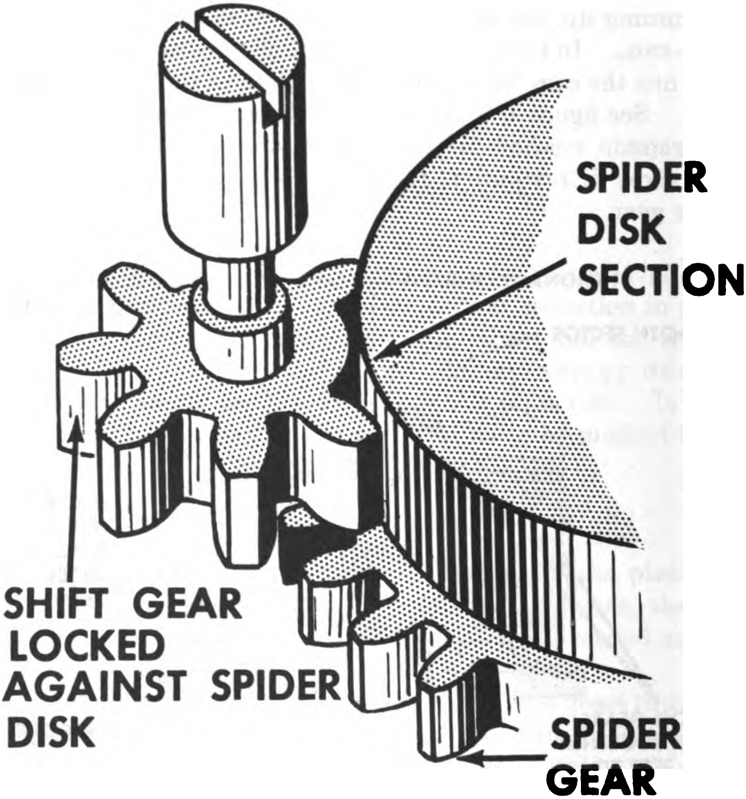


Figure 4-10.—Locking the shift gear.

Locking the Shift Gear

As soon as the shift gear slides out of mesh, it must be locked. If it were free to turn, the input and output lines might not be synchronized when the output cuts in again. To make the gear lock, one tooth is partly cut away or "mutilated" as shown in figure 4–6 (labelled pivot).

When the gear is raised, as shown in figure 4–10, the teeth on either side of the mutilated tooth are held against the side of the spider disc so that the gear cannot turn. The mutilated tooth fits under the edge of the disc. In this position the gear cannot turn and the output is locked.

CAMS

You've learned about some cams already. But there are other cams which appear in many different shapes and sizes and which do so many different jobs that it is sometimes difficult to see exactly what they have in common.

In general, however, they all have some kind of curved path or surface—such as a groove, a ridge, or a contour. The curved path or surface is positioned by the INPUT, and each point on the curve represents a different OUTPUT value.

Applying this general rule in figure 4–11, the cam is a gear with a groove cut in it to represent the curve. Then, as the input gear turns the cam, the follower takes on different positions as the pin slides in the groove. Consequently, the position of the output shaft corresponds to the position of the follower. And every position of the input shaft produces a corresponding output.

Just to give you an example of how a cam like the one in figure 4–11 is used, let us say that the input to the cam is generated range (cR). The output is $\frac{1}{cR}$ which varies in a nonlinear fashion with range—and is used for positioning the gun. The cam curve represents this function, the output will be the function corresponding to each value of range.

That's only one application of the cam. You'll find others as you progress. The constant-lead cam is one of the simplest types you will run across. It has a uniform, or constant-

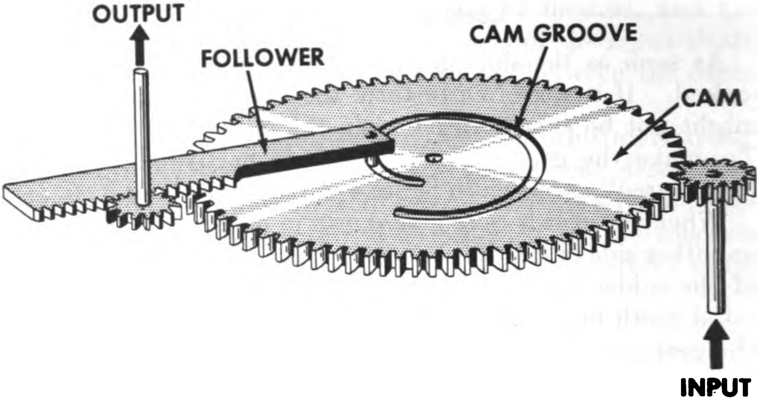


Figure 4-11.—A typical cam.

lead, spiral groove. Each point on the spiral corresponds to an output that is DIRECTLY PROPORTIONAL to the input. For example, if the cam input is own ship's speed in knots, each point on the groove will simply represent a different speed from 0 (zero) to perhaps 45 knots. You'll see it used this way in actual practice.

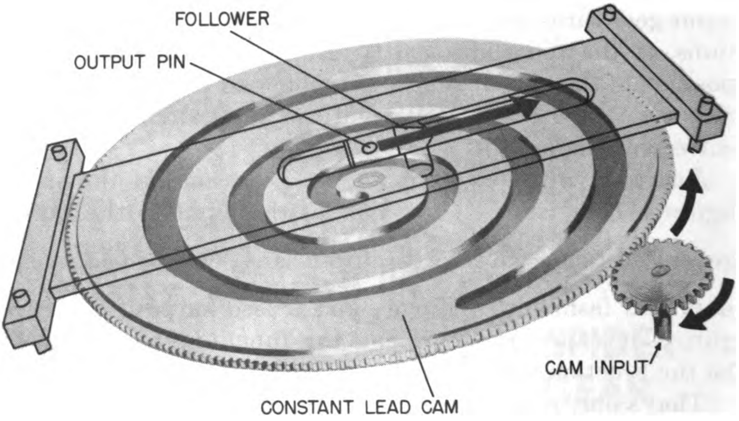


Figure 4-12.—Constant-lead cam.

Study the action of the constant-lead cam in figure 4–12. If the cam is rotated in one direction, the spiral will force the follower block outward from the center, along the slot. However, if the cam is rotated in the opposite direction, the follower block will move inward, toward the center. You can see that the follower itself never travels to the center of the cam, but the output pin is OFFSET on the follower block so that it can be positioned directly over the center of the cam. This is the ZERO POSITION of the output pin. (The offset of the output pin is necessary because, if the pin were allowed to travel to the center of the cam, it would remain there.)

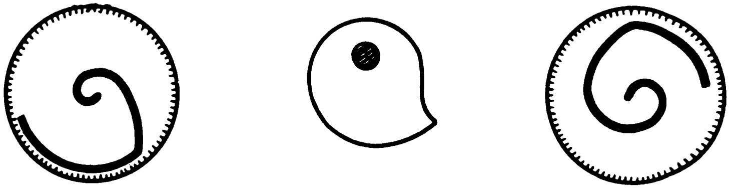
Summing up, the constant-lead cam is simply a special case of the one you see in figure 4–11. Its output is a uniform linear motion of the follower directly proportional to the rotary motion of the input.

Other Cams

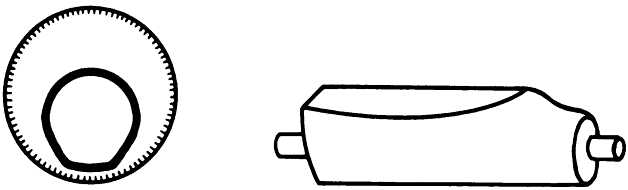
Other cams such as the RECIPROCAL CAM, TANGENT CAM, SQUARE CAM, FLAT CAM, and the BARREL CAM are commonly used in all types of fire-control gear. Some of these cams are illustrated in figure 4–13. The top three cams function much the same. The reciprocal cam produces an output proportional to the RECIPROCAL of its input. For example, if range is the input, then $\frac{1}{\text{range}}$ is the output. Similarly, the tangent cam produces the TANGENT of an angle, whereas the square cam simply mathematically SQUARES the input quantity. You'll study these cams in more detail shortly.

The flat cam can do a job similar to that of the grooved cams. But the follower rolls on its curved edge instead of sliding in a groove. The input rotates the cam about its axis, and the output is positioned by the follower. Also, cams similar to the flat cam can operate mechanical devices to control electric relays or switches. You'll see the flat cam in many sizes and shapes, depending upon its application.

The barrel cam, sometimes called the THREE-DIMENSIONAL or BALLISTIC CAM, has a shaped contour or body. It has two inputs: one rotates the cam about its axis, the other positions



RECIPROCAL CAM FLAT CAM TANGENT CAM



SQUARE CAM BARREL CAM

Figure 4–13.—Cam types.

the follower laterally. The follower positions the output as it rides on the contour of the cam, and its position is a function of the two inputs.

Next, let's take a couple of these cams and study their construction and operation in more detail.

Tangent Cam

The tangent cam takes an angular input and delivers the tangent of the angle to the output. Other trigonometric functions can be obtained in a similar way. The groove will simply take another shape for the various other trigonometric functions.

Figure 4–14A shows how the tangent cam is laid out. It is designed to manufacture the tangent for any angle between 40° and 70°. The groove is cut so that the radial distance from the center of the cam to the center of the groove is proportional to the tangent of the angle. These radial distances are represented in the figure by dark radial lines running out to the groove, corresponding to each angle.

For example, for 55° the tangent is 1.42. That means the groove is located 1.42 units out from the center of the cam, at the 55° position.

Figure 4–14B shows how the cam works. The input angle *A* positions the cam. Then the follower drives the output, which becomes the tangent of the angular input.

From the triangle at the lower right of figure 4–14 you'll see that the tangent of the angle *A* is equal to the ratio of the side opposite to the side adjacent, or *a*/*b*.

Now, go back to 4–14A and notice that, at the 70° position, the groove begins to bend so that its radial distance from the center is constant. This part of the groove is called the "runout."

The cam stops computing at 70° because the tangent of the angle increases without limit as the angle approaches 90°.

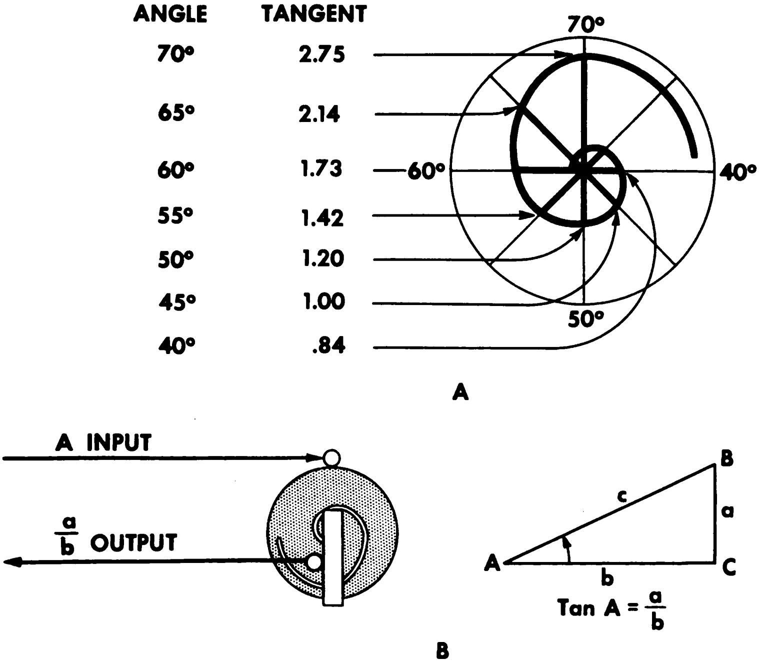


Figure 4–14.—Tangent cam.

For example, another 10° turn would run the groove completely out of the earth's orbit!

The Square Cam

The square cam works like the trigonometric cams, but its groove—instead of producing a trigonometric function—is shaped to square the input quantity. Figure 4–15A shows you how that cam is laid out. Notice that the radial distance from the center of the cam to the groove is proportional to the SQUARE of the input position.

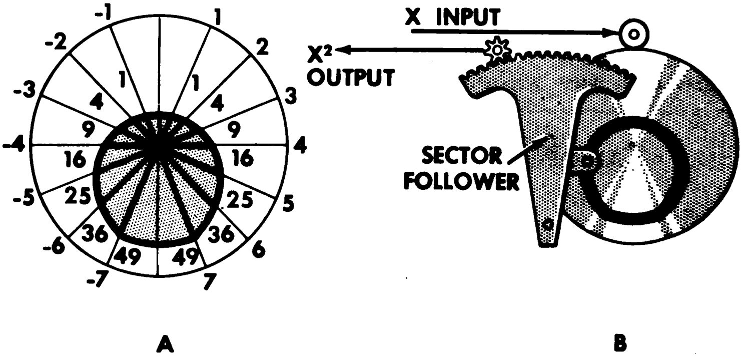


Figure 4–15.—Square cam.

For example, $1^2=1$, which makes the distance from the center of the cam to the groove ONE unit in length, corresponding to the cam-gear position 1. Corresponding to the cam position 2, the radial distance to the groove is FOUR units in length because $2^2=4$, etc. The negative numbers always result in a positive answer because a negative number squared is always positive.

To see how the square cam is hooked up, look at figure 4–15B. The follower usually drives a sector, which positions the output gear and shaft.

In practice, the square cam is used to square any quantity between its limits. For instance, it could square range between 1,000 and 7,000 yards. The gear ratio connecting the cam in the computer can be adjusted, or scaled, to ANY quantity.

It is interesting to notice that the cam is noncomputing between −1 and 1, and between −7 and 7. Squaring numbers less than 1 would result in numbers of smaller and smaller denominations, making the cam inaccurate. On the other hand, the cam would have to be constructed entirely too large in order to be adapted for squaring quantities larger than seven times unity, where unity is 1.

Barrel Cam

The barrel cam is another extremely useful device for computing corrections for gun train and elevation. As you've already learned, it produces a single output which is the function of two inputs. You'll run across it in antiaircraft computers and rangekeepers.

One example of the use of this cam is in the computation of projectile time of flight, *Tf*—the time it takes the projectile to reach the target from the time it is fired. *Tf* is extremely important in that it is used for computation in every computer. In other words, as you already know, the target continues to move during projectile flight. Consequently, all lead angles and other quantities are computed taking *Tf* into account.

Tf is a function of range and elevation. It varies with range and, obviously, as range decreases, *Tf* will decrease. Also, it varies with elevation, because as target elevation increases, the path (trajectory) of the projectile flattens out and *Tf* decreases. This means *Tf* varies with both range and elevation; it also means that it is a NONLINEAR FUNCTION of range and elevation.

The antiaircraft computer must furnish *Tf* for all ranges and elevations. Moreover the *Tf* must be manufactured by the computer instantaneously and continuously. This is exactly where the barrel cam fits in.

Figure 4–16 shows a simplified drawing of the barrel cam and its assembly. Range is put in as a rotary motion of the cam, and elevation positions the follower laterally on the cam by means of a screw. The follower moves in accordance

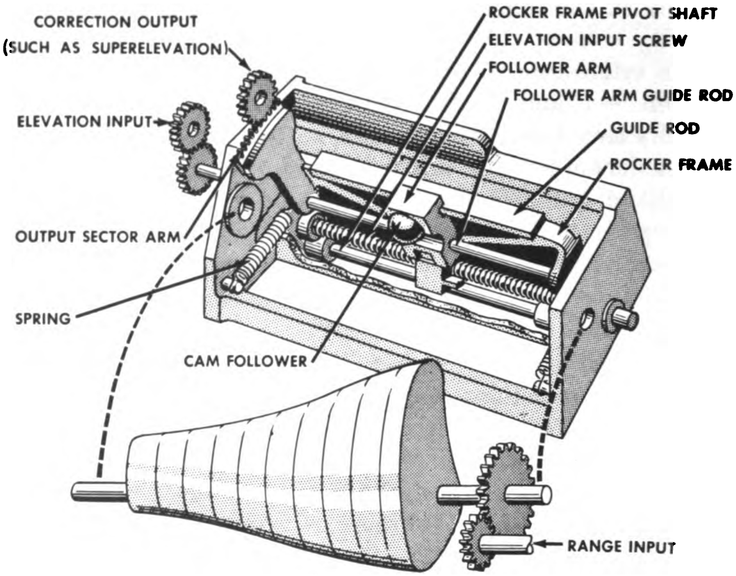


Figure 4–16.—Barrel cam.

with the pattern of the output function cut on the cam. In turn, the follower positions a sector gear to transform the function into a shaft position for transmission throughout the computer.

A study of the diagram in the figure will tell you more than words. The cam is simply inserted under the follower as indicated by the dotted lines. Then the two springs press the follower against the cam, and it is ready to follow the cam as various values of range and elevation are put into the computer.

SUMMING UP

Basic mechanisms play an important part in every fire-control system, and for this reason it will be up to you to help keep them in good condition. Most of the basic mechanisms covered in this chapter cause very little trouble, so as a general rule the best policy is to leave them alone as long as they perform satisfactorily. However, especially with long continuous use, they wear excessively and must be replaced. Also, such devices as the barrel cam must be cleaned occasionally and lubricated with a thin coating of special light grease.

In any event, here's a rule that will always apply: every fire-control instrument has an OP which is designed to tell you how to keep the instrument in good working condition. Take special precautions when using lubricants. NEVER use anything other than what the OP calls for.

QUIZ

1. In a mechanical differential whose $K=2$, what is the output at the spider if one side gear is rotated plus 10 turns and the other is held?
   a. Plus 10 turns
   b. Plus 5 turns
   c. Zero
   d. Minus 5 turns
2. In the mechanical differential of problem 1, what is the output at the spider if one side gear is rotated minus 10 turns and the other held?
   a. Plus 10 turns
   b. Plus 5 turns
   c. Zero
   d. Minus 5 turns
3. In a mechanical differential ($K=2$), what is the output at the spider if one side gear is rotated minus 15 turns and the other plus 10?
   a. Plus 5 turns
   b. Plus 2½ turns
   c. Minus 2½ turns
   d. Minus 5

4. In a mechanical differential ($K=2$), what is the output at the spider if one side gear is rotated minus 10 turns and the other plus 10?
   a. Plus 5 turns
   b. Zero
   c. Minus 5 turns
   d. Minus 10 turns
5. In a mechanical differential whose $K=2$, when one side gear is held and the spider is rotated plus 10 turns, what is the output at the other side gear?
   a. Plus 20 turns
   b. Plus 10 turns
   c. Zero
   d. Minus 10 turns
6. In a mechanical differential whose $K=2$, when one side gear is rotated minus 10 turns and the spider plus 10, what is the output at the other side gear?
   a. Plus 30 turns
   b. Plus 20 turns
   c. Zero
   d. Minus 20 turns
7. In a mechanical differential, what happens to the other end gear when one of the end gears is rotated and the spider held?
   a. The other end gear rotates one-half as far in the same direction
   b. The other end gear rotates an equal amount in the same direction
   c. The other end gear rotates an equal amount in the opposite direction
   d. Nothing
8. The output of the intermittent drive is locked when the
   a. shift gear is up
   b. shift gear is down
   c. shift gear and spider gear are meshed
   d. sliding couple is disengaged
9. A barrel cam is also called a
   a. ballistic cam
   b. constant-lead cam
   c. square cam
   d. tangent cam
10. What are the inputs to a barrel cam?
    a. Range only
    b. Range and bearing
    c. Bearing and elevation
    d. Range and elevation

11. In what type cam does each point on the spiral groove correspond to an output that is directly proportional to the input?
    a. Barrel
    b. Constant-lead
    c. Square
    d. Tangent
12. What type of cam takes an angular input?
    a. Reciprocal
    b. Constant-lead
    c. Square
    d. Tangent
13. The tangent cam computes with angular inputs up to about
    a. 30°
    b. 60°
    c. 70°
    d. 90°
14. The tangent of an angle increases without limit as the angle approaches
    a. 90°
    b. 80°
    c. 70°
    d. 60°
15. What type cam is used to compute time of flight?
    a. Square
    b. Constant-lead
    c. Reciprocal
    d. Barrel
16. What happens to time of flight (*Tf*) as range decreases?
    a. *Tf* increases
    b. *Tf* decreases
    c. *Tf* remains constant
    d. *Tf* slowly increases
17. What happens to time of flight (*Tf*) as target elevation increases?
    a. *Tf* increases
    b. *Tf* decreases
    c. *Tf* remains constant
    d. *Tf* slowly increases

CHAPTER 5

GYROSCOPES

WHERE GYROSCOPES ARE USED

At some time or another you have no doubt watched the gravity-defying antics of a rolling hoop, a spinning top, or a toy gyro without realizing that the properties displayed by these toys are basic in naval gunnery and fire control.

The child's toy—the gyroscope—has grown up to become a part of the "brains" of innumerable fire-control and gunnery instruments. The gyroscope, in its different applications, not only stabilizes the fire-control system, but it helps solve the fire-control problem from the moment the target is sighted until the projectile hits the target. Even the swift and accurate flight of the projectile depends on the stability of a spinning body which is the basis for gyroscopic action.

Ask a torpedoman to show you the inside of a torpedo; you'll find a gyroscope at the controls. It steers the torpedo on a straight course. Its applications are not confined to gunnery, for modern navigation depends on the accuracy of the gyro compass (or master compass).

Nor is stability the only property of a gyro. Let us go back to the hoop that you used to roll and examine it again.

HOW THE GYROSCOPE ACTS

Remember how you used to stand the hoop upright while you were learning to roll it? It fell over every time when it was not moving. But after a few tries you found that the trick was to start it rolling with a flick of the wrist. Then, instead of falling, it rolled along, upright, seeming to defy the laws of gravity.

· Then how did you go about STEERING the hoop? If to turn right you pushed the forward edge to the right, or the after edge to the left—the hoop would promptly fall over. But if you think back, that's not what you did at all. You pushed the TOP of the hoop to the right—and the hoop swung around as neatly as you please.

When a hoop is spinning it behaves quite differently from the way it does when standing still. Any spinning object—a hoop, an engine flywheel, an airplane propeller, the tires of an auto, or a bullet from a rifled gun—has a trait called GYROSCOPIC ACTION.

There are two important peculiarities about the behavior of the gyroscope, and the action of a hoop illustrates both. The fact that a hoop stands upright when it spins is an example of GYROSCOPIC STABILITY. And the way it is steered is governed by the laws of PRECESSION.

Gyroscopic stability means simply that any revolving wheel will keep spinning in the same plane—that is, with its axle headed in the same direction in space—until some outside force moves it out of that plane. The heavier the wheel and the faster it spins, the more firmly it tries to stay in the same plane of rotation and resists any effort to move it from that plane. The force required to turn it out of that plane must be stronger and proportionally greater as either the weight or speed of rotation is increased.

Actually, there's nothing mysterious about gyroscopic stability. It's just an example of one of Sir Isaac Newton's basic laws of motion—"any moving body tends to continue moving in the same straight line and at the same velocity unless acted upon by some exterior force."

The force required to move the body out of that line is proportional to the body's momentum (its mass times its velocity). Each particle of material in the rim of a rotating wheel is trying at all times to move in a straight line. The structure of the wheel pulls it into a circular path, but it keeps trying to stay as nearly in a straight line as possible. Consequently, it keeps rotating in the same plane.

Most of the wheels with which you are acquainted are fastened so that they aren't always free to rotate in any plane. An auto wheel is controlled by the steering apparatus. Normally, therefore, you don't notice the effects of gyroscopic stability, though the tendency of the propeller to keep rotating in the same plane sometimes causes trouble for high-powered airplanes.

But suppose you mount a wheel so that it is free to aline its axis (or axle) in any direction, like the one in figure 5–1. Here the wheel rotates inside a flat loop called the GYRO CASE (the name is different for some applications). The gyro case encloses the entire wheel. Thus the wheel is free to rotate in any plane. The gyro case is so pivoted in a ring—the GIMBAL RING—that the axis of the gyro can swing forward and back. The gimbal ring itself turns on pivots which connect it to the FORK, thus permitting the gyro axis to tilt

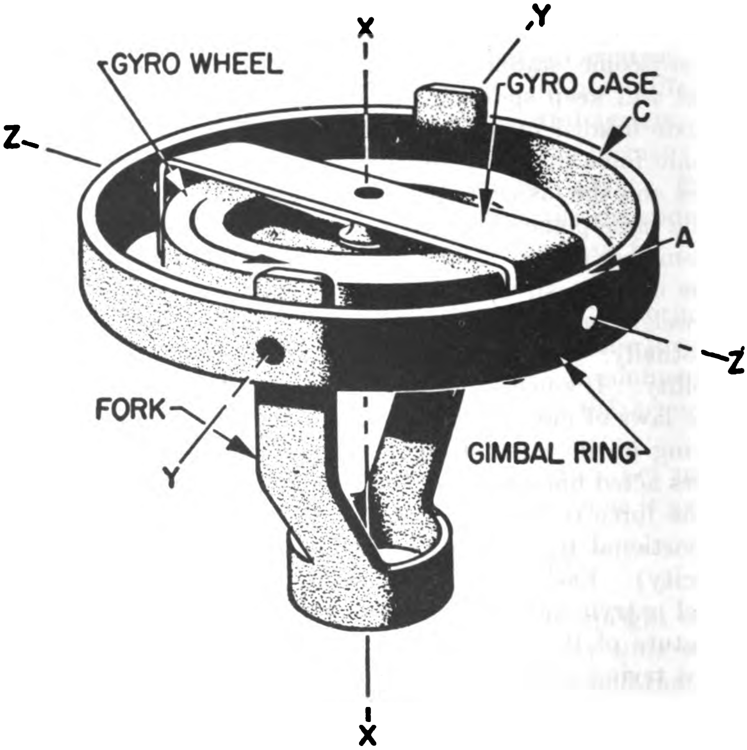


Figure 5–1.—Gimbal mounting of a gyro.

from side to side. This type of mounting is called a GIMBAL MOUNTING.

Regardless of how the fork is placed, the spinning gyro wheel is free to lie in any given plane. That's why it is called a FREE GYROSCOPE in this mounting.

Gyroscopic stability shows up very plainly. Suppose you lined up the spinning gyro wheel so that its axis (x–x) headed toward the North Star. Then you could take hold of the fork and turn it, tilt it, or swing it any way you wished; the gyro axle would continue to point toward the North Star.

Precession

Now try something else. Push down on the gimbal ring at point A at the nearer end of the z–z axis (fig. 5–1). You probably expect the ring to tilt turning around the y–y axis.

But here's the surprise—instead of rotating about the y–y axis as you might expect, the gyro case will turn about the z–z axis. You can see the effect in figure 5–2. This is called PRECESSION—a very important characteristic of a gyro.

Similarly, going back to figure 5–1, suppose you push sideways on the top of the x–x axis (the spinning axle of the gyro), trying to rotate the wheel around the z–z axis. Then, instead of rotating about the z–z axis, the gimbal ring will turn around the y–y axis.

If you push down at point C on the gimbal ring (fig. 5–1), midway between the y–y and z–z axes, you will find that the gimbal ring rotates around the y–y axis, and that the gyro case rotates around the z–z axis. The total effect causes the gyro wheel to turn around a line lying from point C through the center of the gyro wheel.

Now for the next question: In which direction will the gyro precess? There's a simple rule that tells you. It depends on the direction of SPIN of the gyro, and the direction of the applied FORCE.

Here's a rule that applies to all spinning gyros: THE GYRO WILL ALWAYS PRECESS AT RIGHT ANGLES TO THE DIRECTION OF THE APPLIED FORCE.

Look at figure 5–1 again. If you keep pushing down on the gimbal ring at point A, the gyro case will keep turning

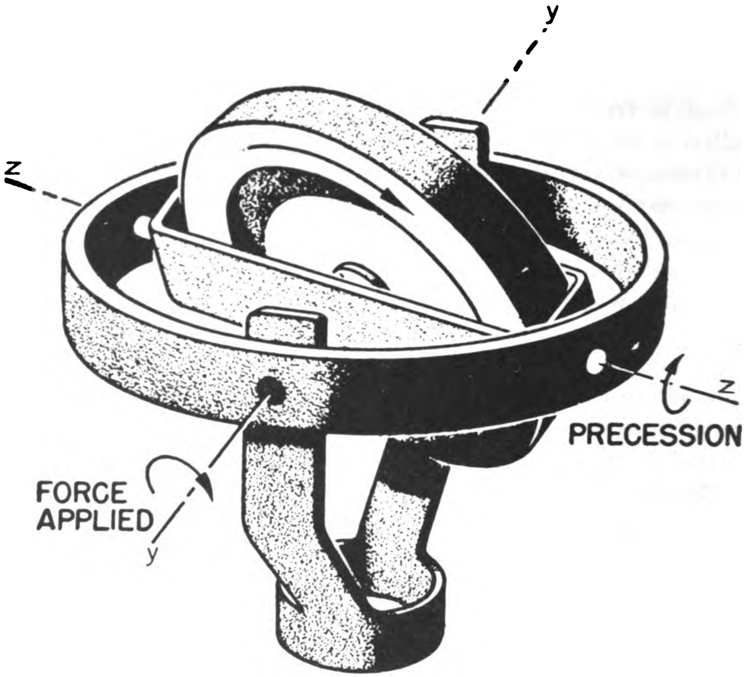


Figure 5–2.—Precession of a gyro.

until the axle of the gyro wheel is horizontal. Then there will be no further precession. At that point the gyro wheel is spinning in the same direction in which the applied force is pushing.

Here's another rule: A GYRO ALWAYS PRECESSES IN A DIRECTION TENDING TO LINE ITSELF UP SO THAT IT SPINS IN THE SAME DIRECTION THAT THE APPLIED FORCE IS TRYING TO TURN IT.

Be sure you understand that most forces, when applied to the gyro mounting, do not cause precession. For instance, you can swing the fork around in any direction, and the motion will merely be taken up in the *y–y* and *z–z* axes. Similarly, a force applied lengthwise along one of the axes will have no effect. ONLY THOSE FORCES TENDING TO TILT THE GYRO WHEEL ITSELF WILL CAUSE PRECESSION. Thus you can see that, if the base of the fork were attached to the deck of a ship, the gyro would have no tendency to precess as the ship rolled and pitched.

By this time you should be pretty curious about what causes this peculiar behavior of a gyro. Actually there's no magic about it at all; it's merely a matter of the addition of vectors.

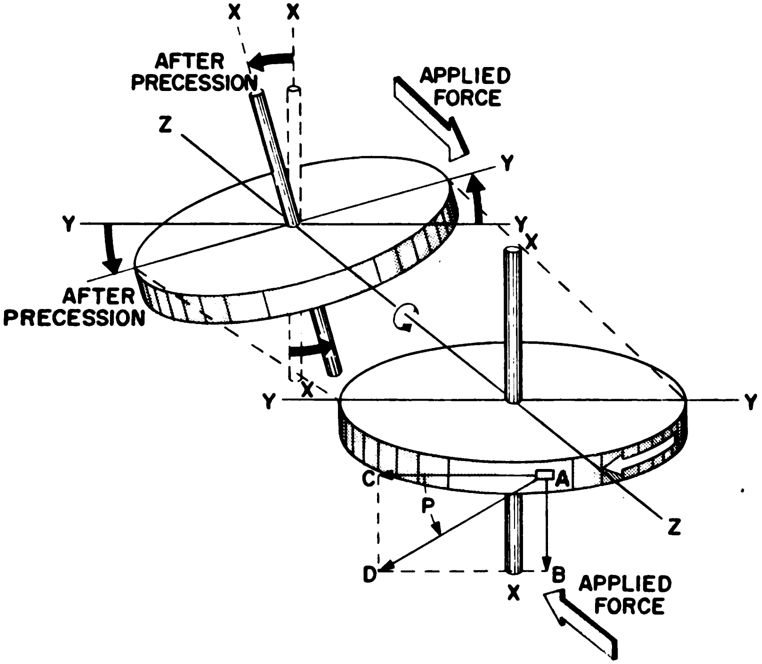


Figure 5–3.—Precision combines two movements.

Figure 5–3 shows a gyro wheel suspended in space. The gimbal mounting has been left off to make the illustration simpler. Notice that a force is being applied to one end of the gyro axle (lower figure), tending to tilt the wheel about the *y–y* axis. Obviously, if the wheel were not spinning, point *A* would start to move in direction *AB*.

But what happens when the wheel is spinning? Point *A* still begins a motion *AB*. But also, it is already moving rapidly in direction *AC*. You already know that when a body has two motions at the same time, they add vectorially. Consequently, the final motion of point *A* will be in direction *AD*.

There's only one way in which point *A* can move in direction *AD*. The spinning axle of the wheel must MOVE to the position shown in dotted lines (top figure). That is, the wheel precesses about the *z–z* axis in a direction at right angles to the rotation which the applied force is trying to cause.

Let's sum it up and see what precession amounts to. You attempt to change the plane of rotation of a wheel. Since the wheel already has a rotation, it moves in a direction which combines the two motions. It keeps precessing until it reaches a position where the applied rotation and the original rotation are in the same direction. Then the effect of the new rotation no longer tends to change the plane of the wheel, and precession stops.

Another important fact to remember is that a gyro will precess only as long as the precessional force is applied. Once the force has been removed the gyro will continue to spin in that position, maintaining its axle fixed in space.

EFFECT OF FRICTION, APPARENT ROTATION, AND LATITUDE

Next, let's see what affects the STABILITY and PRECESSION of a gyro. First, it is impossible to make the gyro mountings frictionless. Friction affects the free movement of the gimbal system. Then, too, the gyro displays rigidity of the plane of rotation in space. But the earth spins through space and the gyro must be located somewhere on the earth. The result is that the gyro appears to rotate 360° a day in a direction which depends on the earth's rotation, and on the LATITUDE in which the gyro is located.

However, if you know that these effects exist, you can correct for them, and the Navy does. Let's examine the effects of friction, first of all, and then determine a corrective force.

Keeping the Gyro Vertical

Go back to figure 5–1 again, and suppose the base of the fork is fastened to the rolling and pitching deck of a destroyer. A roll of the ship tilts the fork, so as to lower the nearest prong. This SHOULD have no effect on the gyro. The gyro case should rotate on the *z-z* axis, and the gyro should stay vertical. But suppose there is a little FRICTION in the *z-z* bearings. This will exert a slight drag on the gyro case, tending to rotate the gyro about the *z-z* axis causing the gyro to precess AWAY FROM THE VERTICAL, about the *y-y* axis.

As you already know, one of the main functions of the gyro in fire control is to maintain a TRUE VERTICAL on a rolling and pitching ship. The instrument which employs the gyro in this way is called a stable element or a stable vertical depending upon its application. In either case they have one thing in common—both instruments accurately maintain a true vertical.

The bearings used in these instruments are nearly frictionless, but there is always enough friction to cause some

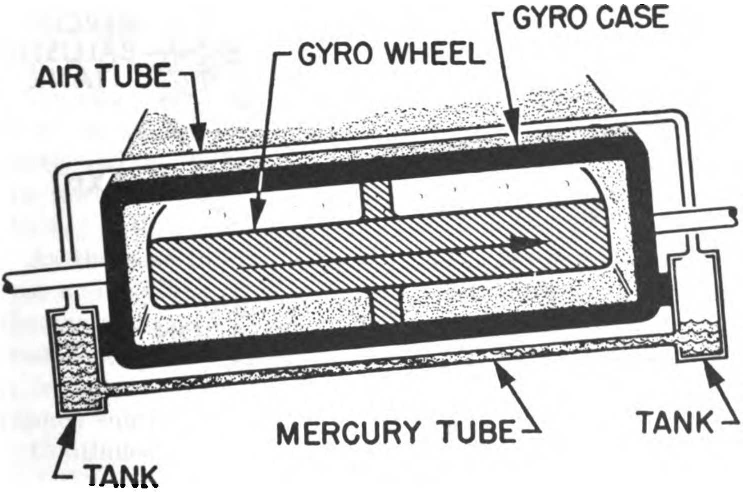


Figure 5–4.—Mercury system of a stable vertical.

trouble. Over a period of time, these slight frictional forces would move the gyro a long way from the vertical. That means you need some corrective force which will bring the gyro back to the vertical when it wanders away. This force is provided by the gyro ERECTING SYSTEM.

The most common type of erecting system consists of two tanks of mercury fastened to opposite sides of the gyro case. The two pools of mercury are connected at the bottom by a small tube. See figure 5–4. An air tube connects the tops of the two tanks in order to prevent the formation of a vacuum.

Figure 5–4 is a schematic view of the gyro case with the gyro tilted away from the vertical. Naturally, the mercury runs from the high tank into the low tank. Therefore the

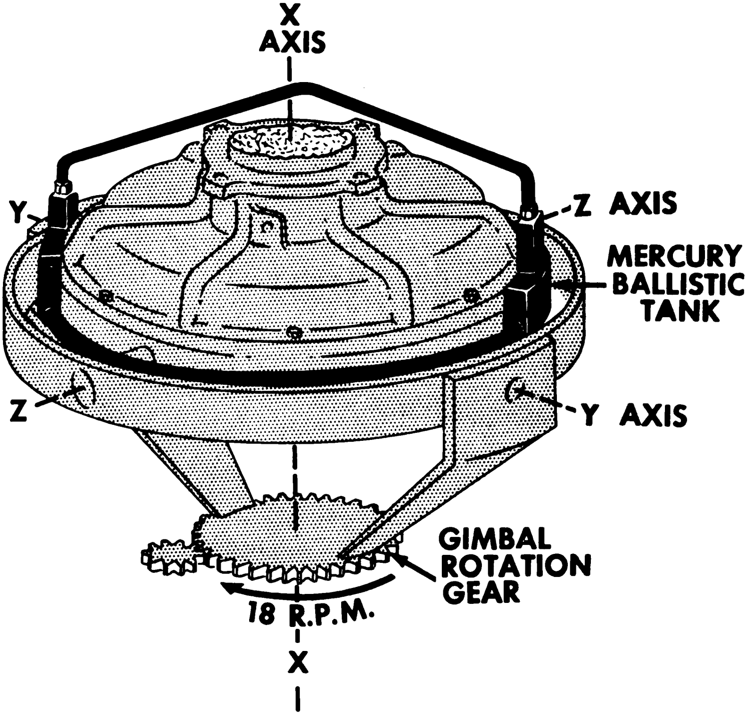


Figure 5–5.—Gimbal rotation.

low tank becomes HEAVIER than the high tank. This sets up a force which tries to tip the gyro farther. The gyro RESISTS this force and PRECESSES to one side—tilting the top of the gyro axle toward you.

So far not much has been accomplished toward getting the gyro back to the vertical—that comes next. Notice that the tube connecting the two tanks is rather small. Therefore the mercury flows slowly. After the case is tilted, it takes nearly a second for the mercury to find its level.

At the same time the fork in this system is being rotated by a small motor about 18 times a minute. (Figure 5–5 is a schematic diagram of the gimbal-rotation system and mercury-ballistic system.) Therefore, during the second that it takes for the mercury to flow into the low tank, the fork and the entire gimbal assembly has rotated 90°. As before, the weight of the mercury is trying to tip the gyro sideways, but this time 90° away from the actual tilt. Thus, the gyro precesses back TOWARD THE VERTICAL.

You will see this more clearly if you think about what happens during one rotation of the fork. The result is indicated in figure 5–6 in which you are looking straight down at the top of the gyro case and the mercury tanks. Understand that this diagram is purely schematic. It is intended to give you an idea of the principle involved, not a complete picture of what happens to a gyro in actual operation.

Suppose that the gyro axle is suddenly tilted toward the north at an instant when the mercury tanks are lined up north and south (fig. 5–6A). Mercury starts to flow into the north tank, but at first no precession occurs because of the lag or time delay in the mercury flow.

As the case rotates, the low tank is moving toward the east and is filling up with mercury. As the lower tank fills, the gyro begins to precess faster and faster in a generally southeasterly direction. By the time the low tank is full, it is headed east (fig. 5–6B) and the gyro is precessing rapidly south.

Continued rotation puts the loaded tank on the high side, and the mercury begins to flow out of it (fig. 5–6C). But the tank is still heavy, and therefore the gyro precesses

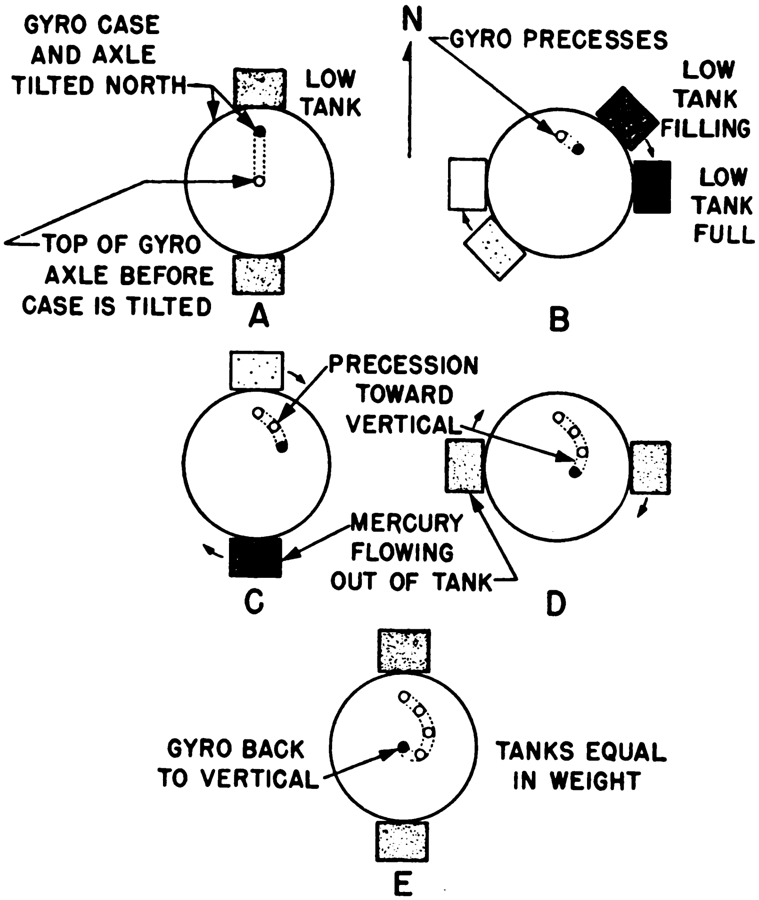

GYRO CASE AND AXLE TILTED NORTH
LOW TANK
TOP OF GYRO AXLE BEFORE CASE IS TILTED
A
N
GYRO PRECESSES
LOW TANK FILLING
LOW TANK FULL
B
PRECESSION TOWARD VERTICAL
MERCURY FLOWING OUT OF TANK
C
D
GYRO BACK TO VERTICAL
TANKS EQUAL IN WEIGHT
E

Figure 5–6.—Effect of rotating the fork.

generally southwest (fig. 5–6D). By the time the tanks are again lined up north and south, the mercury in the two tanks has equalized (fig. 5–6E). The second tank is now the low tank. It begins to fill up, and the entire process repeats.

You can see that the easterly and westerly precessions tend to cancel. The net effect is a precession toward the south, bringing the gyro BACK TO THE VERTICAL.

Thus, you can see that whenever the gyro is started, the mercury system will bring it quickly to the vertical. And at any time the gyro wanders off the vertical, the mercury system will bring it back.

Ask one of the Fire Control Technicians in your division to start the stable element or stable vertical on your ship so you may watch the GIMBAL-ERECTING SYSTEM in action. You'll notice that at first the gyro will precess rapidly towards the vertical. And you'll also notice that the erecting system may require as much as 10 minutes to correct the last few minutes of error. This is because as the gyro comes nearer to the true vertical, less mercury flows from one tank to the other during a rotation of the gimbals. Consequently the precessional force is small and the rate of precession is very slow. In some gyro systems—the master gyro compass, for example—it may take as long as 24 hours for the gyro to finally settle down in its true position.

Let's review the main purposes of the gimbal-erecting system of a stable element or stable vertical. First of all, it brings the gyro to the true vertical when the gyro is started. Second, it compensates for the effect of friction and other irregularities in the gimbals which could cause the gyro to precess away from the vertical.

There are several other types of erecting systems used with gyros. You will learn about these in later Fire Control Technician's courses. If you are in doubt about the mercury system, go back over the text for it is the basic erecting system of modern fire-control gyro stabilizers.

Latitude Correction

A few pages back we mentioned that there are two kinds of action which tend to pull a gyro out of the vertical. One of these is the random effect of bearing friction and other similar irregularities. You have seen how a mercury-erecting system overcomes this effect.

In addition to these random actions, the ROTATION OF THE EARTH has a continuous effect on the gyro. Remember that gyroscopic stability (also called rigidity of plane) means that a gyro axle tries to maintain a fixed direction in space.

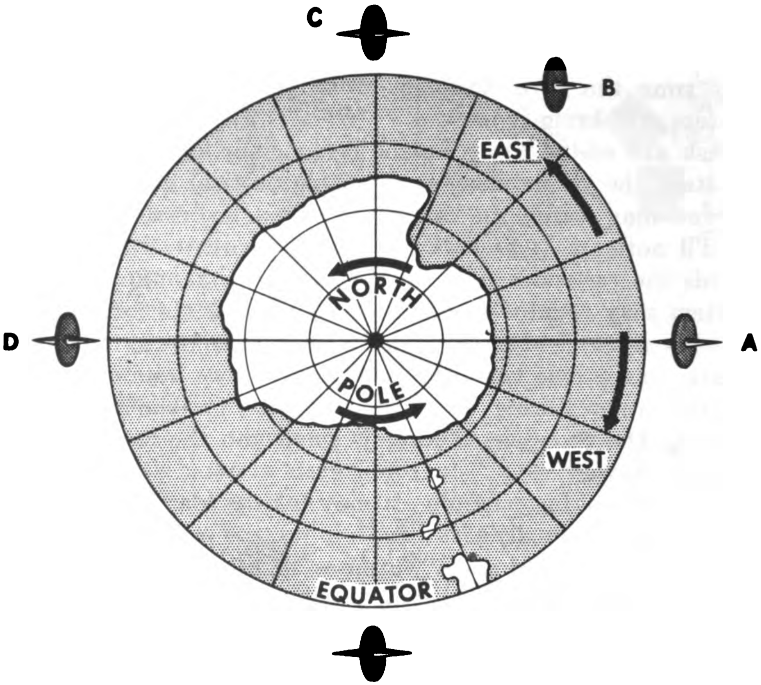


Figure 5–7.—Apparent rotation at the equator.

But the earth, as it rotates toward the east, is rolling under the gyro. Therefore, to an observer standing on the earth, the gyro appears to keep tipping westward.

This effect is shown clearly in figure 5–7. The figure is a view of the earth as it would appear if you were looking down on the north pole. Imagine that a gyroscope has been erected on the equator at point *A* with its axis vertical (perpendicular to the surface of the earth), and that because the gyroscope has frictionless bearings and no erecting system, you must rely on gyroscopic stability to keep it vertical. After a few hours, the rotation of the earth will move point *A* to the position marked *B*.

The gyro still heads in the same direction IN SPACE, but it is no longer VERTICAL. Its axis is no longer perpendicular to the earth's surface at that point. To anyone standing on the earth it appears to be leaning to the west. After 6 hours, when the earth has made a quarter turn, the gyro will be horizontal, as at *C*. After 12 hours (at position *D*) it will have turned completely over and will be upside down. And after 24 hours the gyro will have made a complete revolution. In other words, the gyro is tilting WESTWARD at a rate of 15° per hour.

The mercury-erecting system of the stable vertical won't quite prevent all of this tilt. The gyro, therefore, must be made to precess EASTWARD at 15° per hour.

Now when the gyro is truly vertical, the mercury system causes no precession. The mercury affects the gyro only

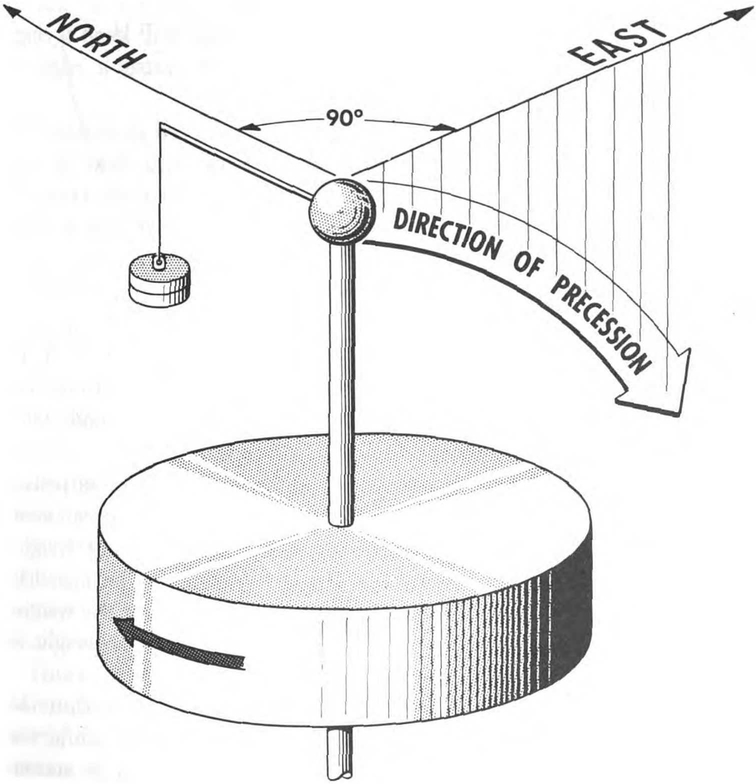


Figure 5-8.—Correction weight.

when the gyro is tilted. And so, if we were to rely on the mercury system to produce the required eastward precession, the gyro would always lean slightly to the west. It would NEVER be truly vertical, as it should be for efficient fire control. An error would always persist, being maximum at the equator, and gradually decreasing to zero at either pole.

When a gyro is vertical, therefore, you correct for the effect of the earth's rotation at all times by applying to the gyro some force that will cause a steady eastward precession. This means that in dealing with Navy stable elements or stable verticals the top of the gyro axle must be pushed northward.

This can be done by extending a small arm northward from the top of the axle and hanging a weight on the north end of the arm as in figure 5–8. The weight will keep trying to tip the axle northward, and this will cause a regular westward precession.

Up to now it's been assumed that the gyro is located at the equator. A little thought will show you that if the gyro were placed at the north or south pole, the rotation of the earth would have no tendency to move it out of the vertical. So you would expect that at points on the earth between the equator and the pole, the gyro would tilt westward at a speed LESS than 15° per hour. This is true, and figure 5–9 shows you why. If a gyro is vertical at *A*, it will move to point *B* in 12 hours, and will tilt through an angle of (180°−2×latitude of *A*)—instead of through 180° as it would at the equator.

This means that the precessional force should be adjusted as you sail toward higher or lower latitudes. You can slow down the precession by moving the compensating weight inward on the arm, closer to the gyro axle. The arm has markings on it to show you the correct position of the weight for any latitude (fig. 5–10). For this reason the weight is called LATITUDE-CORRECTION WEIGHT.

One final point—how are you going to be sure that the latitude-correction arm is always headed north while the ship and the stable vertical are turning? This is accomplished by mounting the arm on the rotor of a small synchro

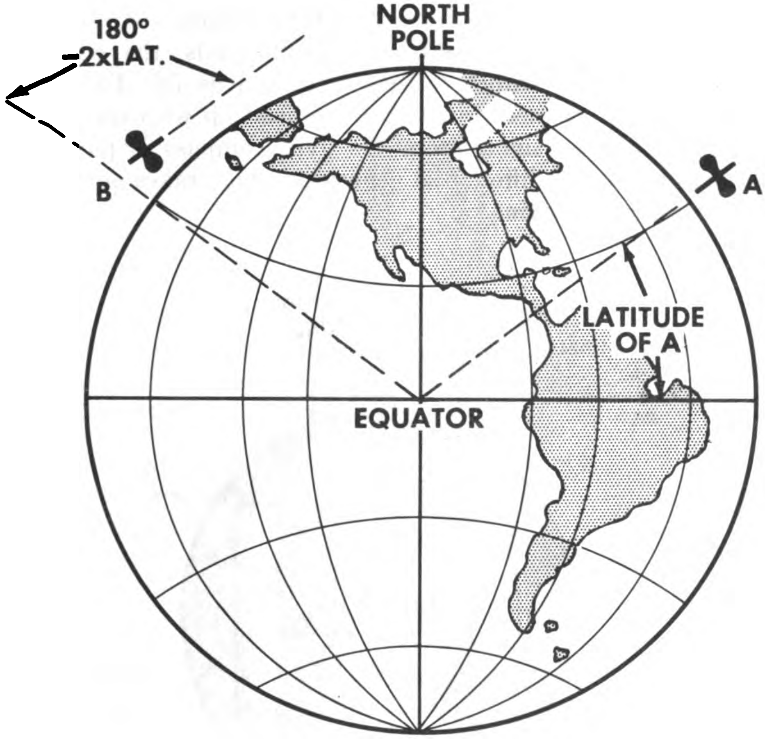


Figure 5–9.—Effect of earth's rotation at mid-latitudes.

motor attached to the gyro case. The synchro receives own ship's course from the ship's gyro compass. Thus the rotor of the synchro will always maintain an angle with the electrical zero of the synchro stator equal to the angle between the north mark on the compass card and the lubber's line (ship's head). If the electrical zero of the stator were always on the fore-and-aft line of the ship, then the arm would always point north.

However, the gyro assembly, as you know, is rotating at about 18 r. p. m. Therefore, in order to keep the arm on north, the synchro rotor must turn backward, relative to its stator, at 18 r. p. m. So the signal from the gyro compass is passed through a SYNCHRO-DIFFERENTIAL GENERATOR which has its rotor geared to the rotating fork of the gyro, thereby eliminating the effect of gimbal rotation.

Finally, as you will learn in later manuals, the entire stable element or stable vertical is turned as the director trains to keep its measuring elements lined up with the line of sight. So the signal from the gyro compass is passed through a SECOND differential generator which takes out the effect of director train.

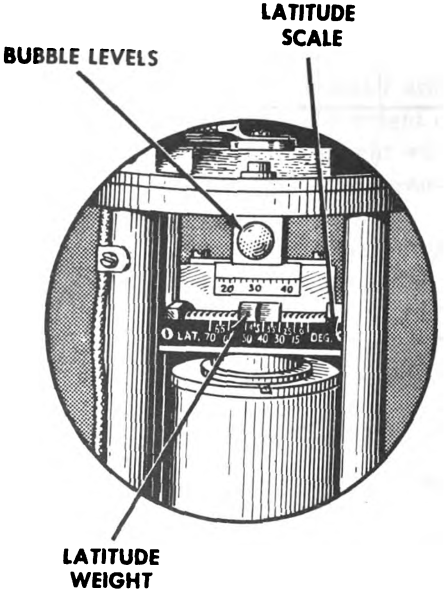


Figure 5–10.—Latitude-correction weight.

Thus, the synchro rotor receives (in reverse) all the movements of the gyro compass and the director, with the result that the zero mark on the latitude-correction arm always heads north.

Figure 5–11 shows the appearance of the gyroscope and its case. Notice, in the cutaway portion, that the GYRO WHEEL is the rotor of a 3-phase a-c induction motor. The case forms the motor stator. This gyro-driving motor is

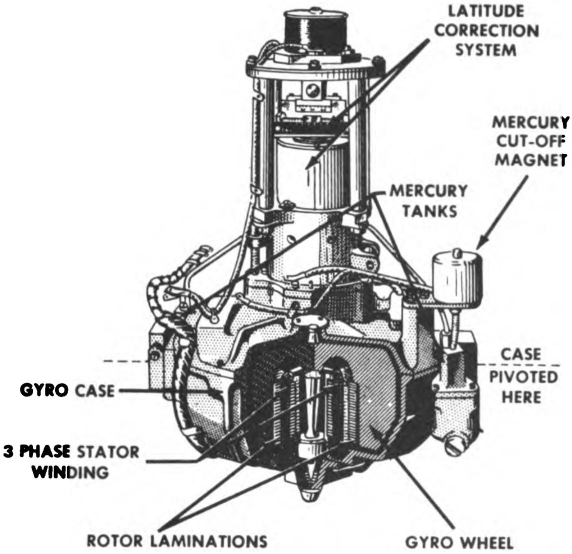


Figure 5–11.—Gyro case of the stable vertical.

operated by 70-volt 146-cycle a-c obtained from a special motor generator set. The 146-cycle current is used in order to permit high gyro speeds. The maximum speed which can be obtained from a 60-cycle current with an induction motor is only 3,600 r. p. m., but 146 cycles permit nearly 146 times 60, or 8,760 r. p. m.

In your FT2 and FT1 training manuals you will learn more about how the gyro is used in the stable element and stable vertical.

These manuals will explain how the stable vertical measures the amount of roll and pitch of the ship, and how it manufactures the correction angles for the rangekeeper.

As has been stated, different systems use different types of erecting systems. However, the mercury gimbal-erecting system is the most common. You will learn about other types later in your fire-control career. But no matter what type of gyro-erecting system you encounter, its basic purpose will be the same. It helps the gyro to find and maintain a true vertical position, which is used to correct gun orders for the rolling and pitching of the ship.

Learn the basic gyro theory and the rest is easy. No matter how the gyro is used, it will display the same familiar characteristics—RIGIDITY OF PLANE OF ROTATION, AND PRECESSION.

RATE-OF-TURN GYROS

A good example of another use of the gyro in fire control is in the lead-computing gun sight. This sight uses a pair of RATE-OF-TURN GYROS. A rate-of-turn gyro is nothing more than a simple gyroscope which is installed to take advantage of PRECESSION. This precession is carefully measured in terms of bearing and elevation tracking rates which, after

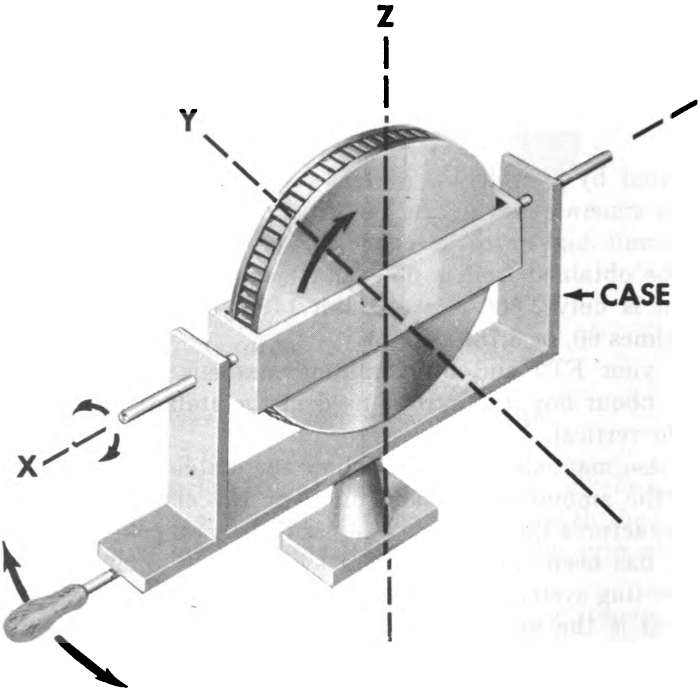


Figure 5–12.—Rate-of-turn gyro mounting.

certain modifications, becomes gun-elevation and gun-train lead angles.

That is a pretty broad statement, so let's look at a typical problem of a lead-computing gun sight. Consider the case of a jet fighter sweeping by your ship at a 1,000-yard range. His bearing rate would be so fast that it would tie a mechanical computing system in knots trying to calculate gun-train and elevation orders.

But the fact remains that these targets are dangerous and have to be knocked down. This means that some type of computing mechanism must be used; a type which is still faster than the one using the mechanical components you have studied in previous chapters. And the GYRO is the answer.

You will remember that, among other factors, the rate of precession of a gyro is proportional to the external force applied to the gyro.

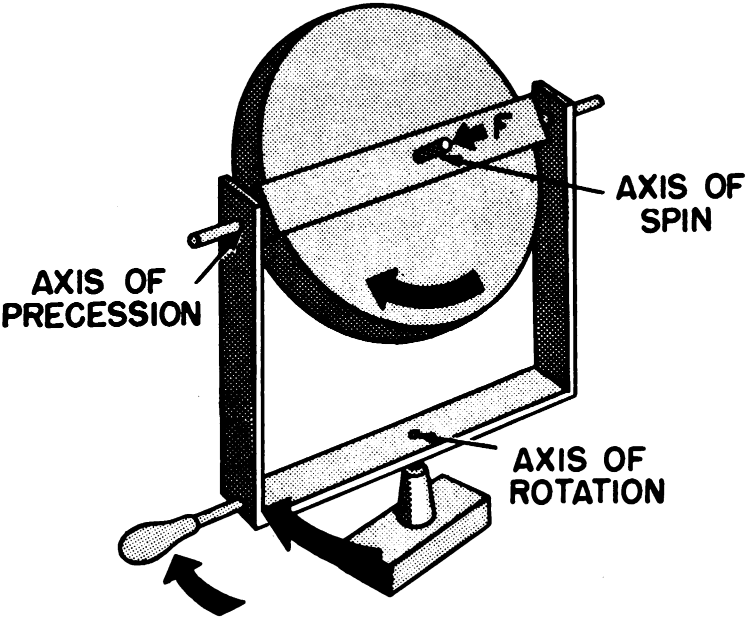


Figure 5–13.—The rate-of-turn gyro precesses.

Look at the gyro installation in figure 5–12. The gyro is spinning in a vertical plane. It has freedom of movement in two coordinates only—its spin axis and the *x-x* axis. Movement about the *z-z* axis is controlled by positioning the case with the attached handle.

If you attempt to change the plane of rotation of the gyro by rotating the case about the *z-z* axis, the gyro will precess about the *x-x* axis as shown in figure 5–13. Offhand, the gyro may not appear to be obeying the laws of precession. But stop to consider this for a minute. Attempting to turn

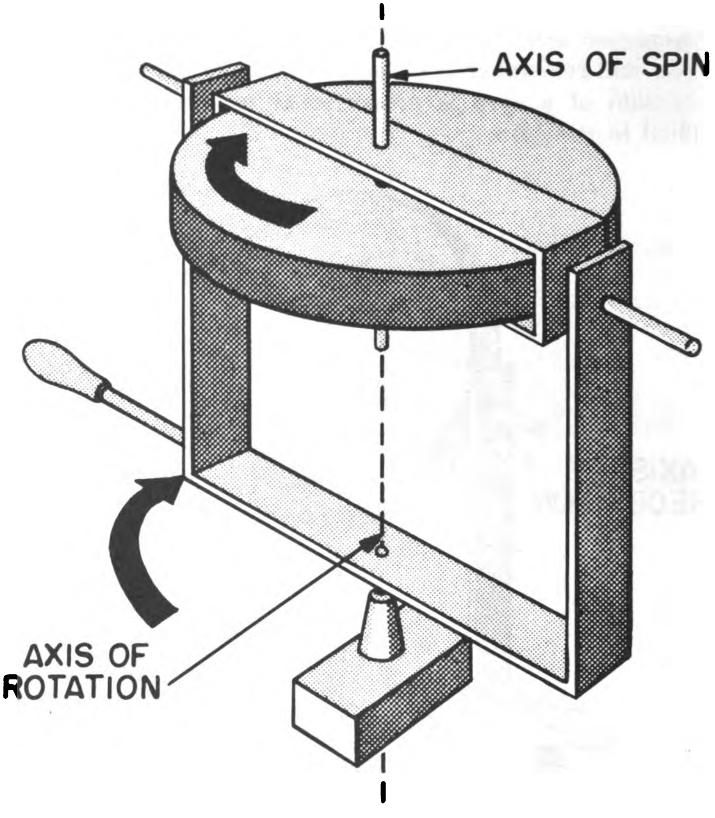


Figure 5–14.—The rate-of-turn gyro precesses.

the gyro case is the same as applying horizontal force on the spin axle, as shown by the arrow *F*.

You know that a force applied at *F* will cause the gyro to precess at right angles to the force. Likewise, attempting to turn the gyro case will cause the same result. The gyro will precess at right angles to the force. Attempting to turn the gyro case will cause the same result. The gyro will precess as shown by the arrows, around the *x-x*, or precession axis.

Since the rate of precession is proportional to the applied force, you can increase the rate of precession by increasing the speed with which you are moving the handle (fig. 5–14). In other words, you have a RATE-OF-TURN GYRO. The FASTER you turn the handle, the MORE the GYRO will PRECESS, because the *amount of precession is proportional to the rate of turn*.

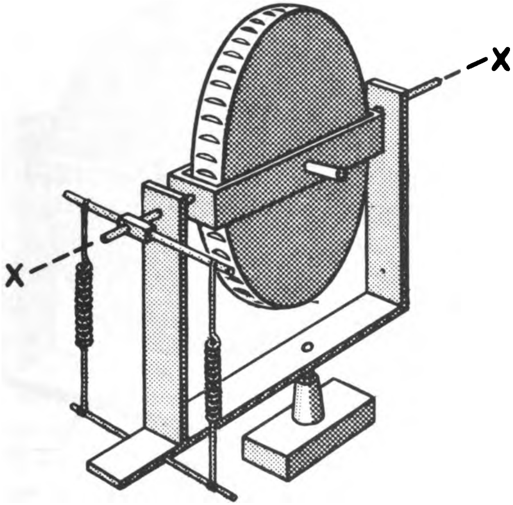


Figure 5–15.—Restrained rate-of-turn gyro.

This characteristic of a gyro, when properly controlled, fits the requirements of a high-speed lead-computing gun sight. Let's see what is necessary to control the gyro properly.

In figure 5–15 is shown the method of restraining (controlling) the precession of a gyro to permit the calculation of a lead angle. A pair of springs have been attached to the crossarm on the *x-x* shaft. These springs serve to restrain the free precession of the gyro. The gyro is harnessed to produce some useful work.

We can say that as a gyro precesses, it exerts a certain force which is proportional to the momentum of the spinning wheel and the applied force.

For example, suppose you rotate the gyro case at a speed which is proportional to applying a horizontal force of 2

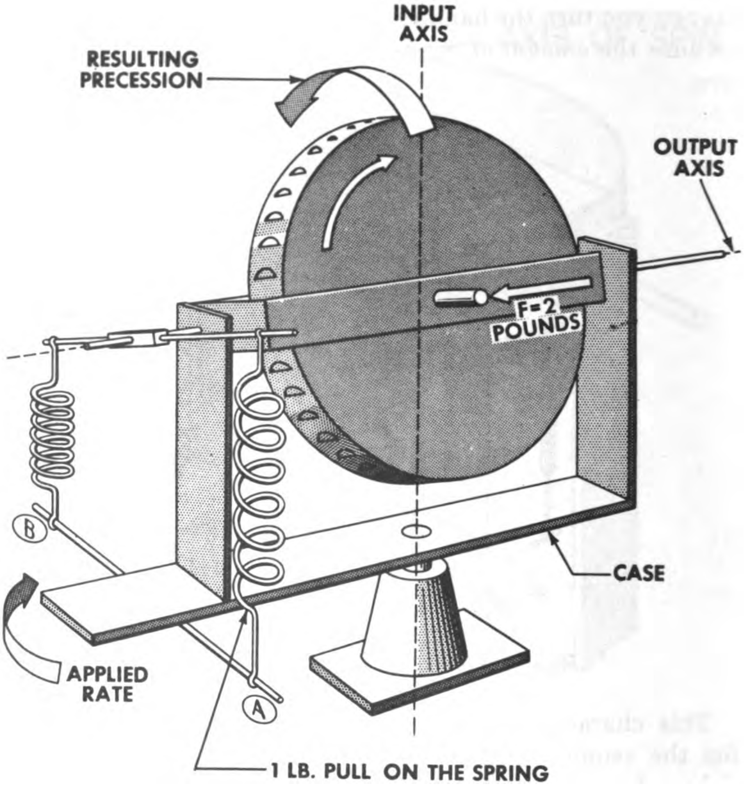


Figure 5–16.—Precession of a restrained rate-of-turn gyro.

pounds at *F* as shown in figure 5–16. Obviously, the gyro will precess; and as it does, it will cause the crossarm to pull up on spring *A* with a certain force—say 1 pound. This would vary with the length of the crossarm.

If you continue to turn the gyro case at this rate, the precession of the gyro will continually exert a pull on the spring. More precisely, the gyro will precess until 1-pound pull of the crossarm is exactly counterbalanced by the tension of the spring.

As turning continues at the same rate, the gyro will continually try to precess farther, but since its pull is balanced by the tension of the spring, it will remain in a fixed position as shown in figure 5–16. That is, it will remain in the precessed position as long as you continue to rotate the case at the same, constant speed.

When you stop moving the handle, it is equivalent to removing the force at *F*, and the gyro stops precessing. The spring is still exerting a pull, however, so it pulls the crossarm back to the horizontal.

Suppose you rotated the case twice as fast as before. That would be equal to a 4-pound force at *F* and a resulting 2-pound pull by the crossarm on spring *A*. So the gyro would precess twice as far before the tension on the restraining spring equalled the pull of the crossarm.

Boiling it down, the faster you rotate the gyro case the farther the gyro will precess before the pulls of the crossarm and spring are equal, and the gyro comes to rest.

Outside of a few refinements, that's about all there is to a simple lead-computing gun sight. Instead of turning the gyro case with a handle, the case is mounted on a 20-mm gun as is shown diametrically in figure 5–17. Then as you train the gun to follow a fast moving target, the gyro precesses. Notice how the precession of the gyro moves the pointer across the scale. By calibration of the scale, the pointer can be made to indicate lead angle.

In your chapter on lead-computing gun sights you will learn more of how these gyros are actually used in a sight. You will learn that the tension on the restraining springs is calibrated according to range to the target. Instead of

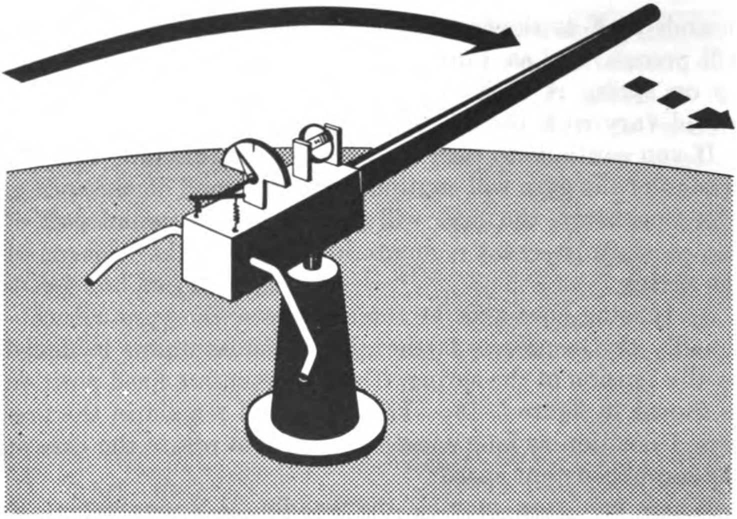


Figure 5–17.—The gyro indicates the lead angle.

pointers indicating lead angle on a scale, you will learn that precession of the gyros moves a complicated system of linkages and mirrors causing an illuminated reticle to be displaced by the correct lead angle. You will also learn how this reticle is used in correctly laying the gun.

The Navy has many different kinds of sights that depend on the gyro to compute lead angle. But the basic principle of all of them depends on the same two characteristics of a gyro—RIGIDITY OF PLANE OF ROTATION, AND PRECESSION.

QUIZ

Select the answer (a, b, c, or d) which BEST completes the statement or answers the question.

1. The tendency of any revolving wheel to keep spinning in the same plane until some outside force acts upon it is called
   a. gyroscopic action
   b. steering ability
   c. gyroscopic stability
   d. precession
2. Precession is caused by
   a. forces which tend to tilt the gyro wheel
   b. forces applied lengthwise along one of the axes
   c. most forces applied to the gyro mounting
   d. swinging the fork in any direction
3. What accounts for the gyro axle's trying to maintain a fixed direction in space?
   a. Continuous precession
   b. Outside forces
   c. Earth's rotation
   d. Gyroscopic stability
4. At the equator the earth's rotation will cause a gyro to
   a. tilt to the east
   b. tilt to the west
   c. tilt to the north
   d. remain vertical
5. At the equator how many degrees per hour will the earth's rotation cause a gyro to tilt?
   a. 0°
   b. 15°
   c. 90°
   d. 180°
6. At which of the following places would a gyro require the MOST precessional force to counteract the earth's rotation?
   a. North pole
   b. 45° north or south latitude
   c. Equator
   d. South pole
7. At which of the following places would a gyro require the LEAST precessional force to counteract the earth's rotation?
   a. North pole
   b. 45° north latitude
   c. Equator
   d. 45° south latitude

8. The weight on the gyro axle arm of the stable element has markings to show
    a. true north and true vertical positions
    b. correct positions for any latitude
    c. the amount of eastward precession
    d. changes in elevation
9. An arm with a weight is extended from the stable element gyro axle to
    a. cause a steady westward precession on the gyro
    b. tip the gyro slightly to the north
    c. balance the gyro in all latitudes
    d. counteract the westward tilt of the gyro
10. The zero mark on the latitude correction arm of the gyro axle always heads
    a. north
    b. east
    c. south
    d. west
11. The stable element is righted by the combined action of the
    a. mercury ballistic tanks and gimbal rotation
    b. mercury ballistic tanks and latitude-correction weight
    c. latitude-correction weight and gimbal rotation
    d. latitude-correction motor and mercury ballistic tanks
12. Any friction which might cause the stable element to precess away from the vertical is compensated by the
    a. latitude-correction weight
    b. latitude-correction motor
    c. gyro-erection system
    d. friction compensation weight
13. The rate-of-turn gyro measures bearing and elevation tracking rates by using the
    a. bearing and elevation lead angles
    b. speed of rotation
    c. amount of precession
    d. rate of precession
14. As the rate-of-turn gyro precesses, it exerts a force against the springs which is proportional to the
    a. momentum and mass of the spinning wheel
    b. momentum and speed of the spinning wheel
    c. momentum of the spinning wheel and the applied force
    d. mass of the spinning wheel and the applied force
15. The rate-of-turn gyro will remain in the precessed position as long as the case is
    a. in accelerated motion
    b. rotated at the same constant speed
    c. held stationary
    d. tilted forward about the spin axis at a constant speed

CHAPTER 6

LEAD-COMPUTING SIGHTS

SHORT-RANGE FIRE CONTROL

Think for a minute about such ballistics as DRIFT—a correction in deflection to compensate for the drift of the projectile, measured in the horizontal plane, WIND CORRECTIONS—corrections due to effect of wind on the projectile and SUPERELEVATION—the angle the gun must be elevated above the predicted line of sight to compensate for the curvature of trajectory in the vertical plane. These ballistics have only small effects at short ranges, in fact, some of them may be ignored with little effect on the accuracy of the solution of the fire-control problem.

The machines that compute the ballistic corrections necessary to position long-range guns accurately have a

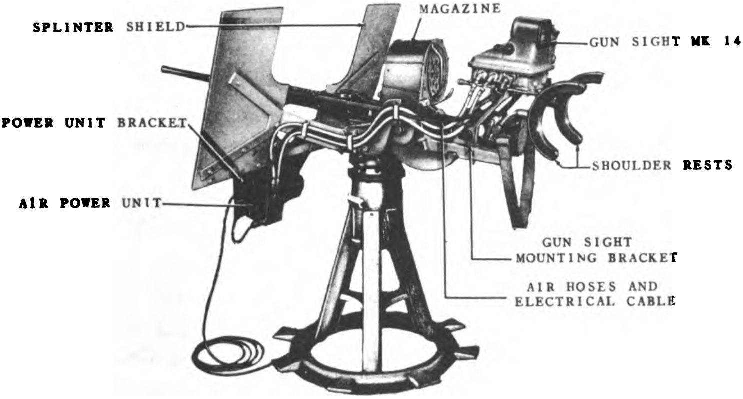


Figure 6–1.—20-mm gun with lead-computing gun sight.

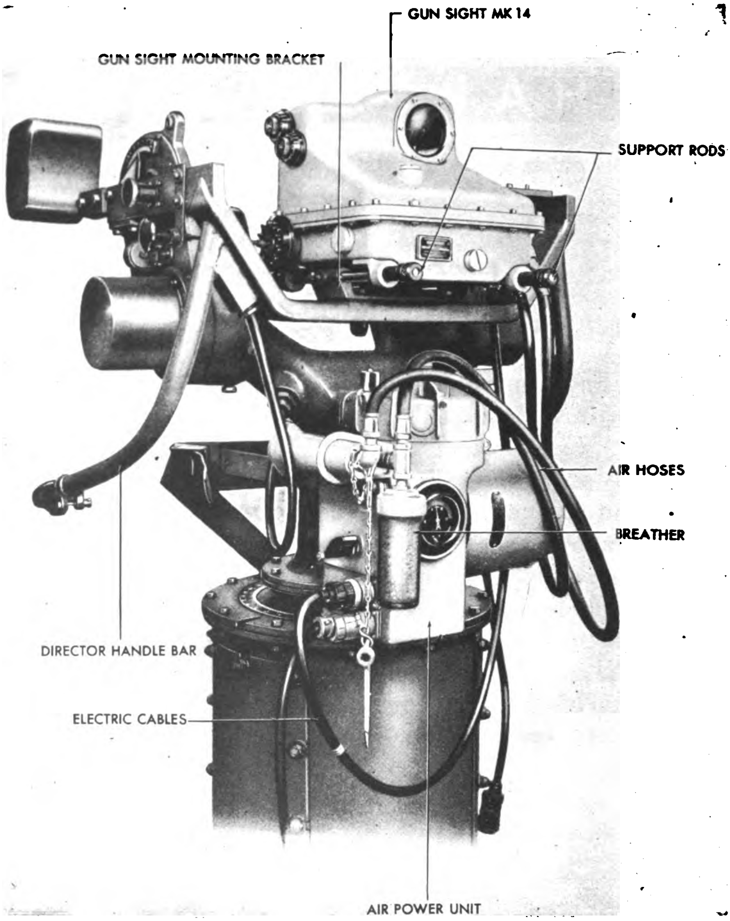


Figure 6–2.—Gun director with lead-computing sight.

comparatively slow solution time, and therefore are far too slow for calculating the gun orders for fast-moving short-range targets. Thus, early in World War II, the Navy developed light-weight, compact, lead-computing gun sights to do that job. These sights are mounted directly on the gun or on a director pedestal as shown in figures 6–1 and 6–2.

The simplest of these gun sights can compute the entire short-range fire-control problem with the single input of

PRESENT RANGE. Range is estimated by the operator or supplied by radar or other means. In either case, the simpler sights have facilities for introducing range by manual means only.

In the study of gyros you found that the heart of the lead-computing gun sight is the rate-of-turn gyro. Let's briefly review the action of this gyro and see how it is adapted to the lead-computing gun sight.

RATE-OF-TURN GYRO

You may recall that as a gyro precesses, it exerts a certain torque which is proportional to the momentum of the spinning wheel and the applied torque. For example, suppose you rotate the gyro case as shown in figure 6–3. Then the gyro will precess to the right; and as it does, it will cause the crossarm to pull up on the left spring. If you continue to turn the gyro case at the same rate, the precession of the gyro will continually exert a pull on the spring. The gyro will precess until the crossarm is exactly counterbalanced by the tension of the spring. The gyro will try to precess farther, but since its pull is balanced by the tension of the spring, it will remain in a fixed position as shown in figure 6–3. That is, it will remain in the precessed position as long as you continue to rotate the case at the same, constant speed.

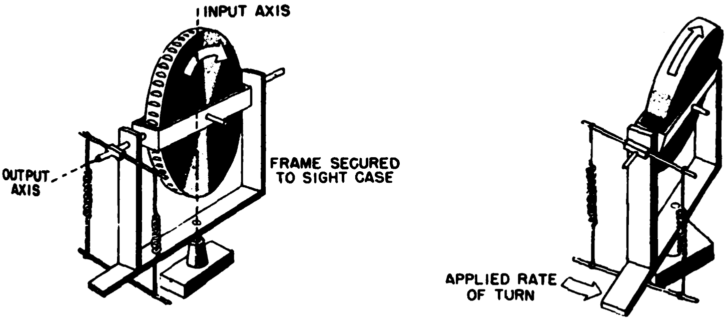


Figure 6–3.—Precession of a restrained rate-of-turn gyro.

When you stop moving the case, it is equivalent to removing the torque, and the gyro stops precessing. The spring is still exerting a pull and pulls the crossarm back to the horizontal.

Suppose that you now rotate the case twice as fast as before—you double the rate of turn. The gyro will then precess twice as far before the tension on the restraining spring equals the pull of the crossarm. Thus, the faster you turn the case, the farther the gyro will precess before the pulls of the crossarm and spring are equal, and the gyro comes to rest.

Outside of a few refinements, that's about all there is to a simple lead-computing gun sight. Instead of turning the gyro case with a handle, the case is mounted on a gun as shown in figure 6–1. Then as you train the gun to follow a fast-moving target, the gyro precesses and moves a system of linkages and mirrors causing an illuminated reticle to be displaced by the correct lead angle.

LEAD-COMPUTING SIGHT

The lead-computing sight approaches the solution to the short-range fire-control problem by measuring the components of relative motion DIRECTLY. This greatly reduces the solution time. Let us examine how the lead-computing gun sight measures the lead angles resulting from target motion with no ballistics present and with the gun stationary.

When a target proceeds along a course as shown in figure 6–4, it generates an angle while moving from its present position to its future position during the time of flight of the projectile. It is this angle which must be computed when the target is at its present position to give advance information as to the target's future position. This angle is the total lead angle (prediction angle) resulting from target motion. The prediction angle can be broken down into two components—the TRAVERSE and ELEVATION lead angles (fig. 6–4).

The traverse lead angle is measured in a plane containing the trunnion axis of the gun and the line of sight to present target position. The elevation lead angle is measured in a

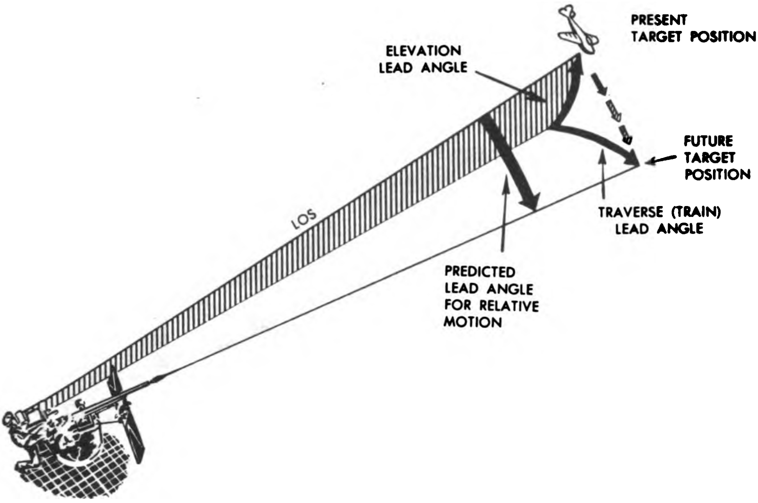


Figure 6–4.—Elevation and traverse lead angles with no ballistics present.

plane perpendicular to the traverse plane (and in turn, the deck plane) containing the line of fire.

The solution of these two angles is made by the lead-computing sight simultaneously. The gyro system positions a pair of mirrors so that the line of sight LAGS the line of fire, both in elevation and traverse.

Computation for these angles is made on the basis of present range (the only input in this case) and the ANGULAR RATES generated by tracking in elevation and traverse. The computation is performed by two gyros mounted in the sight so that their spin axes are at right angles. A gyro mounted so that its spin axis coincides with the trunnion axis of the gun measures the traverse lead angle. Another gyro mounted with its spin axis perpendicular to the trunnion axis measures the elevation lead angle.

Figure 6–5 shows the arrangement of the traverse and elevation rate-of-turn gyros along with the linkages to the mirrors. The gyro on the left is the traverse gyro and the one on the right is the elevation gyro. The parts associated with the gyros will be discussed along with a continued dis-

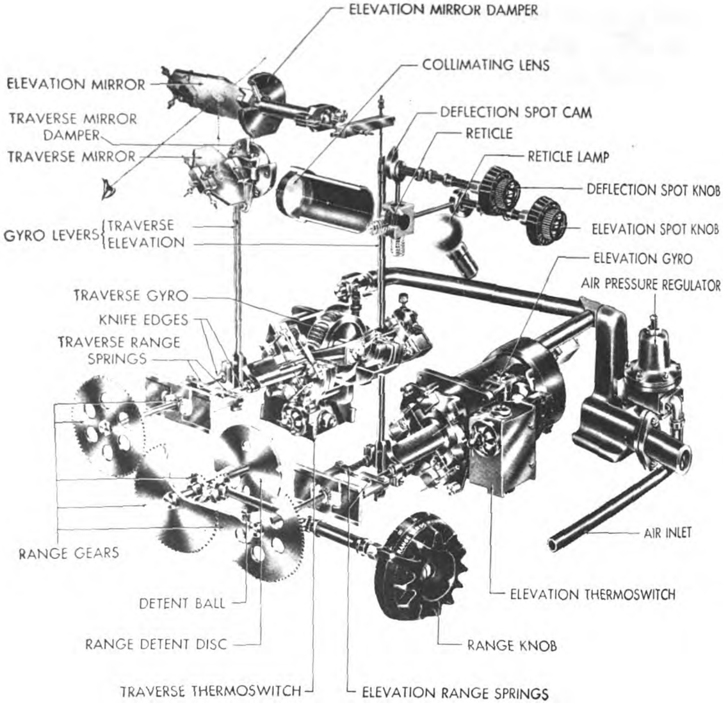


Figure 6–5.—Lead-computing gun sight schematic diagram.

cussion of the elements of the antiaircraft short-range fire-control problem.

Optical System

The optical line of sight in the lead-computing gun sight is determined by an illuminated reticle pattern which consists of two concentric circles as shown in figure 6–6. To superimpose the reticle image onto the pointer's field of view so that it will appear to lie in the same plane as the target, light from a reticle lamp is projected through the reticle and then through a collimating lens to make the rays of light from the reticle parallel to each other. The parallel rays from the collimating tube are reflected upward from the silvered traverse mirror to the transparent elevation mirror and then to the pointer's eye.

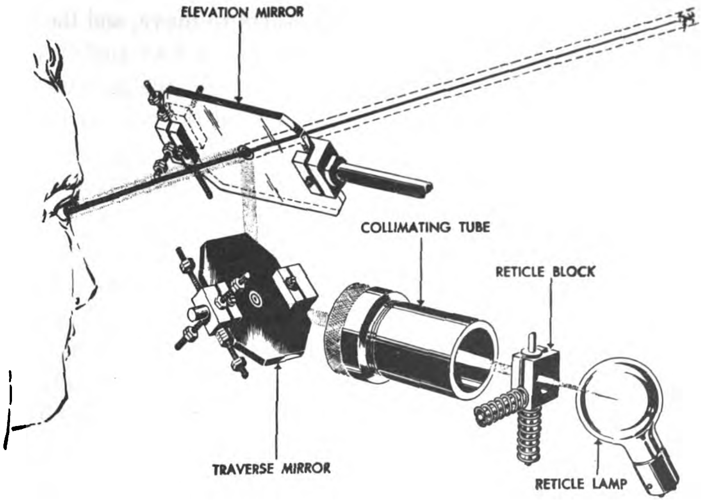


Figure 6-6.—Optical system.

Because rays of light from a distant source (the target) are very nearly parallel, the collimated reticle image appears to lie in front of the sight at the same distance as the target. Thus, there is no parallax between the reticle image and the target, and movement of the pointer's eye will produce no relative movement between the reticle and target.

Let us explain the action of the reticle, the line of sight, target, and gun. Consider them to be stationary as shown in figure 6-7A. Here the line of fire and the line of sight coin-

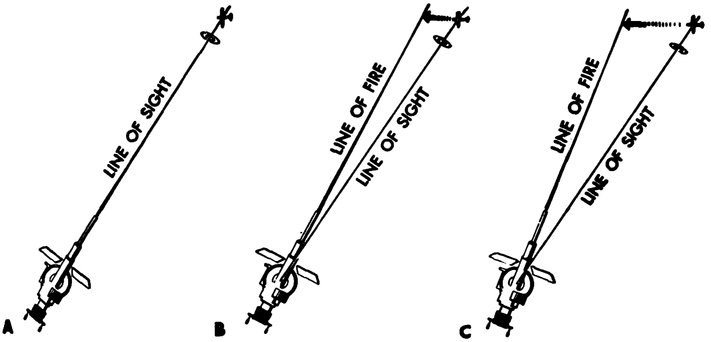


Figure 6-7.—Tracking with disturbed line of sight.

cide. In figure 6–7B the target starts to move, and the line of fire and line of sight move with it. A lead angle is now required because of the target motion and the precession of the gyros cause the reticle to lag behind the gun barrel.

As the target approaches its final velocity, (fig. 6–7C) the computing mechanisms will cause the reticle (and consequently, the line of sight) to lag behind the line of fire by an amount equal to the computed lead angle.

In this manner the gun (or director) is caused to move directly to the computed train and elevation, while the line of sight remains on the target. A gun sight operating in this manner has what is called a DISTURBED LINE OF SIGHT.

The angle of tilt of the silvered mirror is controlled by the traverse gyro in proportion to the required traverse lead angle, and the angle of the transparent mirror is controlled in the same manner by the elevation gyro. See figure 6–5.

Tilting the traverse mirror will cause the reticle beam to fall on the elevation mirror to one side or the other of center depending upon the direction of tilt of the traverse gyro as shown in figure 6–8. The elevation mirror, being controlled in the same manner by the elevation gyro, will act to shift the

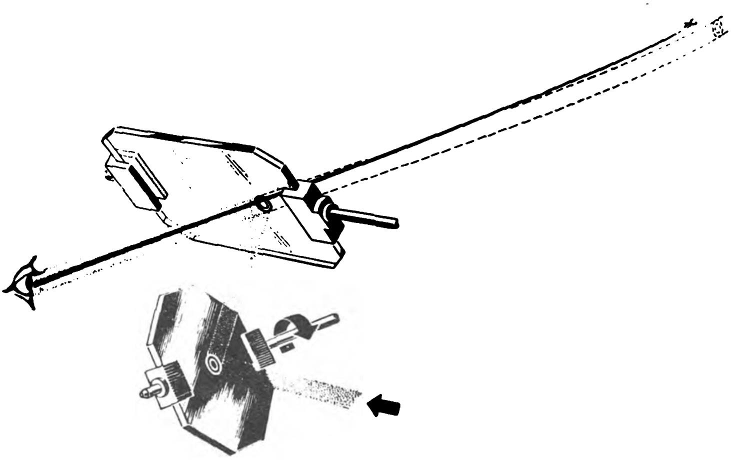


Figure 6–8.—How the traverse mirror moves the reticle image.

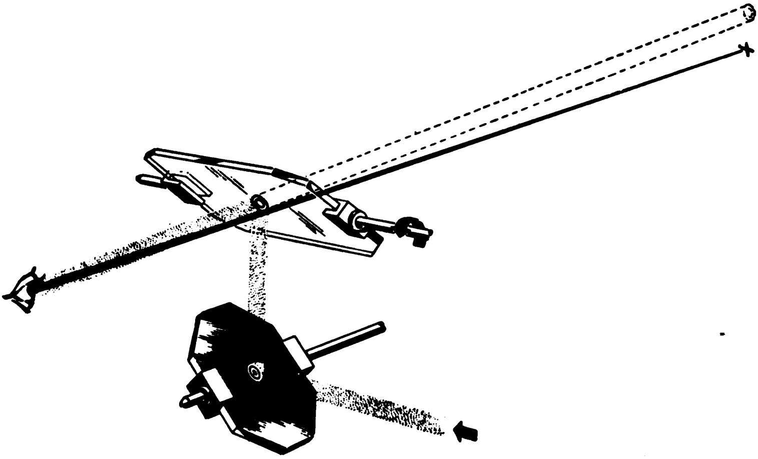


Figure 6–9.—How the elevation mirror moves the reticle image.

angle of reflection of the reticle beam up or down (fig. 6–9), causing the reticle image to move through the elevation lead angle.

For a target having a component of motion in both planes as in figure 6–4, each mirror is tilted to produce its proper component of lead angle; the resultant lag of the reticle image produces the total or predicted lead angle.

Computing Lead Angle

When you track with a lead-computing sight, the computing mechanism of the sight must translate the traverse and elevation angular velocities of the LOS into angular displacement. This is accomplished by the rate-of-turn gyros in a manner to be discussed presently.

If the time of flight to future target position is known, the mathematical computation of a lead angle is easy—you simply multiply the applied rate of turn of the sight case by time of flight, *Tf*. Stating by formula:

Gun-lead angle $= Tf$ (in seconds) × Applied Rate-of-Turn (degrees/sec.).

It immediately appears that if accurate information of *Tf* is available, the problem reduces to a simple multiplication.

But as you learned, the computation of *Tf* gets quite involved: first, you have to compute total change in range which, when added to present range, gives the range to future target position (advance range); then *Tf* is computed as a function of advance range.

The problem solved by the lead-computing sight is greatly streamlined by eliminating the direct computation of advance range and *Tf*, and substituting approximate values. This simplifies the computing mechanism and greatly shortens the time required to solve for the predicted gun-lead angle. An understanding of these approximate methods entails further study of the rate-of-turn gyro and its control mechanisms.

Referring to figure 6–3 again, as soon as the gyro wheel starts to tilt, one spring is stretched and the other is compressed, as has been explained, and the gyro will continue to tilt about the output axis until the torque exerted by the springs is exactly counterbalanced by the precessional torque of the gyro. The amount by which the gyro rotor tilts is governed as follows:

1. The tilt is directly proportional to the precessional torque exerted by the gyro.
2. The tilt is directly proportional to the applied angular velocity produced by tracking the target.
3. The tilt is inversely proportional to the stiffness of the restraining springs.

Now you can see that if the tilt angle of the gyro output axis is governed by both 2 and 3 (above) simultaneously, the angular motion must be proportional to the product of effects 2 and 3. Expressed mathematically—

$$\text{Output angle} = \text{Constant} \times \frac{\text{Applied Rate of Turn}}{\text{Restraining Spring Stiffness}}$$

Going a step further, if you let *Tf* be proportional to the constant over the stiffness of the restraining springs, the result will be closely equal to the required lead angle.

It is now apparent that the approximate value of *Tf* can be applied to the rate-of-turn gyro by regulating the stiffness of the springs.

Examining the problem a little closer, you know that there is a corresponding value of *Tf* for each value of advance range. But the value of advance range is unknown and is not computed by the sight. So all values of *Tf* are based on present range and modified by the constant in the above formula.

If the plane is going away, there is no danger of attack. Lead-computing sights, therefore, are designed for attacking planes. That is, it is assumed that the range rate is always negative, and advance range is always shorter than present range. Thus, for every value of present range put into the sight, there is an approximate value of advance range (and in turn, *Tf*) introduced by regulating the stiffness of the restraining springs. Let us examine an actual mechanism used for this purpose.

Range System

Although the restraining spring (range spring) setups vary for different types of lead-computing sights, they all have the same operating principle. For this reason only those springs incorporated in the sight under discussion here will be presented.

Figure 6–10 shows the range system for the elevation and traverse gyros. You can see how the system couples to the gyros in figure 6–5.

The range-adjustment system must provide a means of varying the spring restraint on the elevation and traverse gyro output axes, which, as described in the last section, must be varied in proportion to *Tf* based on an approximate value of advance range. This approximate value of advance range is introduced into the sight by properly calibrating the range dial at the range knob input (fig. 6–10), taking into account the restraint offered for different positions of the springs.

By means of a gear train, rotation of the externally located manual range knob turns equally two identical spur gears (fig. 6–10). One of these spur gears controls the elevation gyro range springs, and the other controls the traverse gyro springs.

A yoke, supporting knife edges, is attached to the output axis of the gyro. These knife edges rest between cantilever

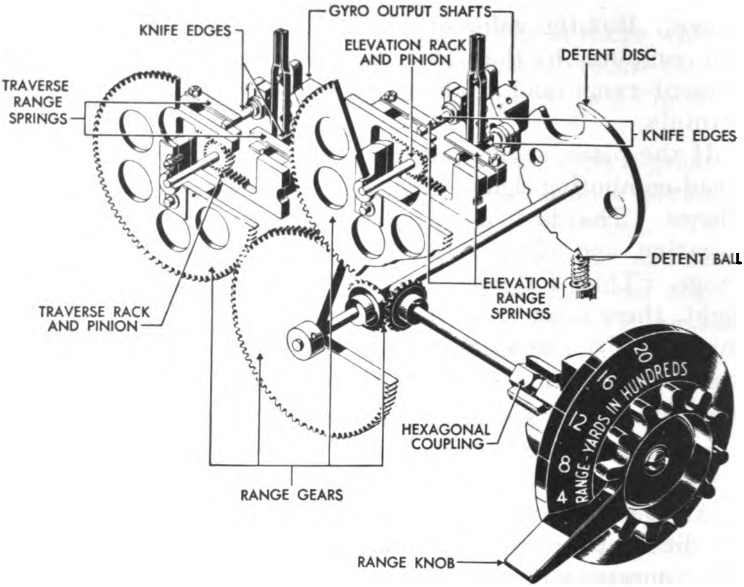


Figure 6–10.—Range system.

range springs. Rotation of the range spur gear moves the parallel cantilever range-spring supports together or apart by means of a rack and pinion arrangement.

When the range knob is turned to a low setting, the two spring assemblies are moved closer together, increasing the spring restraint on the gyro. Thus, precession of the gyros is decreased. When the range knob is turned to a high setting, the spring supports are shifted apart, allowing greater spring deflection of the knife edges under a given angular rotation of the gun sight. This permits the gyro to precess to the larger angle required for the longer range.

The range knob discussed here is graduated in 400-yard increments. A spring-loaded detent engages the detent disc at each graduation (fig. 6–10). Operation of the range knob rotates the disc. Because each type sight is designed for specific ballistics, and the range-spring systems vary in construction, the range knobs are not always calibrated as shown.

Mirror Linkages

The precessional movement of the elevation and traverse gyros is not equal to the corresponding lead angles. The springs are kept stiff enough so that precession is much smaller than the lead angle—the actual precession of either gyro is never more than 1° or 2°. This is necessary because, as you know, the gyro measures rate of turn about an axis at right angles to the spin axle. For example, if the traverse gyro is allowed to tilt a large amount, it measures a rate of turn not around the traverse axis, but around an axis rotated several degrees from it. Obviously, this would introduce serious error.

It is the purpose of the mirrors and the gyro lever system to AMPLIFY the lead angles measured by the restrained gyros in

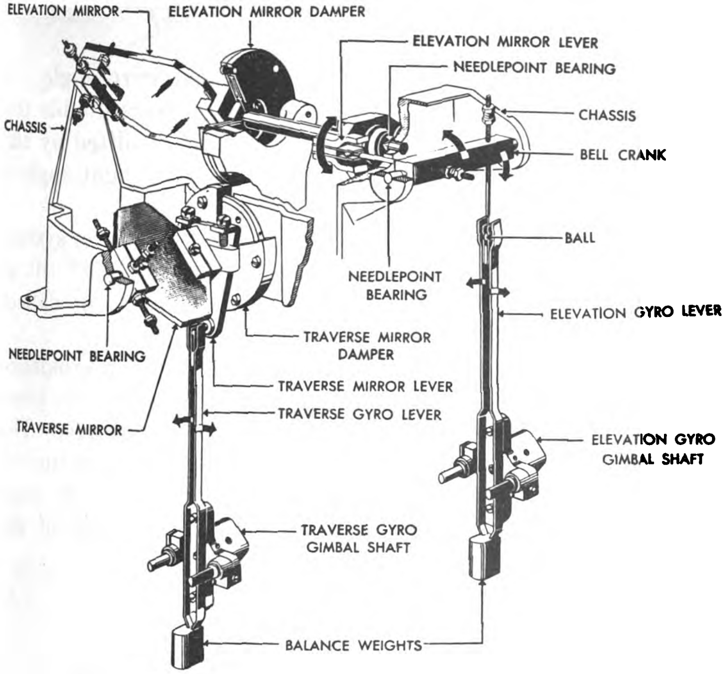


Figure 6–11.—Mirror linkages.

order to produce the required lead angle. A certain multiplication factor is obtained by the ratio between the lengths of the gyro lever arms and the mirror cranks in figure 6–11. Thus, the lever system furnishes part of the multiplication.

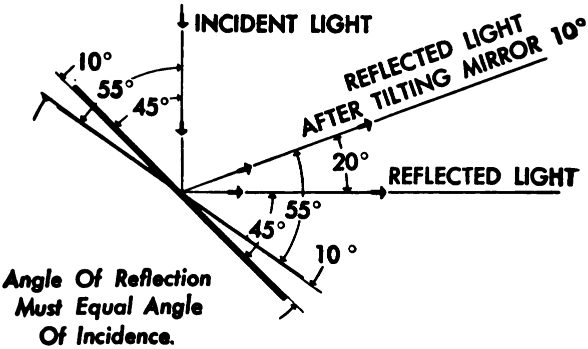

INCIDENT LIGHT
10°
55°
45°
REFLECTED LIGHT AFTER TILTING MIRROR 10°
20°
REFLECTED LIGHT
55°
45°
10 °
Angle Of Reflection Must Equal Angle Of Incidence.

Figure 6–12.—Optical multiplication of angles.

The mirrors themselves also multiply the gyro angle. A study of figure 6–12 will show that the mirrors double the angle. For example, if the mirror position is shifted by 10° relative to the incident light ray, the reflected light angle is changed by 20° as shown.

The overall multiplication of the linkage and mirror system shown in figure 6–11 is about 10—that means a 2° tilt of either the elevation or traverse gyro will elevate or deflect the optical line of sight by 20°.

The balance weights shown in figure 6–11 counterbalance the weights of the respective lever arms so as not to place additional, unwanted torques on the gyro output axis. The dampers on the elevation and traverse mirror shafts smooth out mirror vibration and random motion. You'll learn more about damping while studying the damping of the gyros themselves.

Ballistic Corrections

Once the lead angle for relative motion between target and own ship has been computed, it is necessary to add the

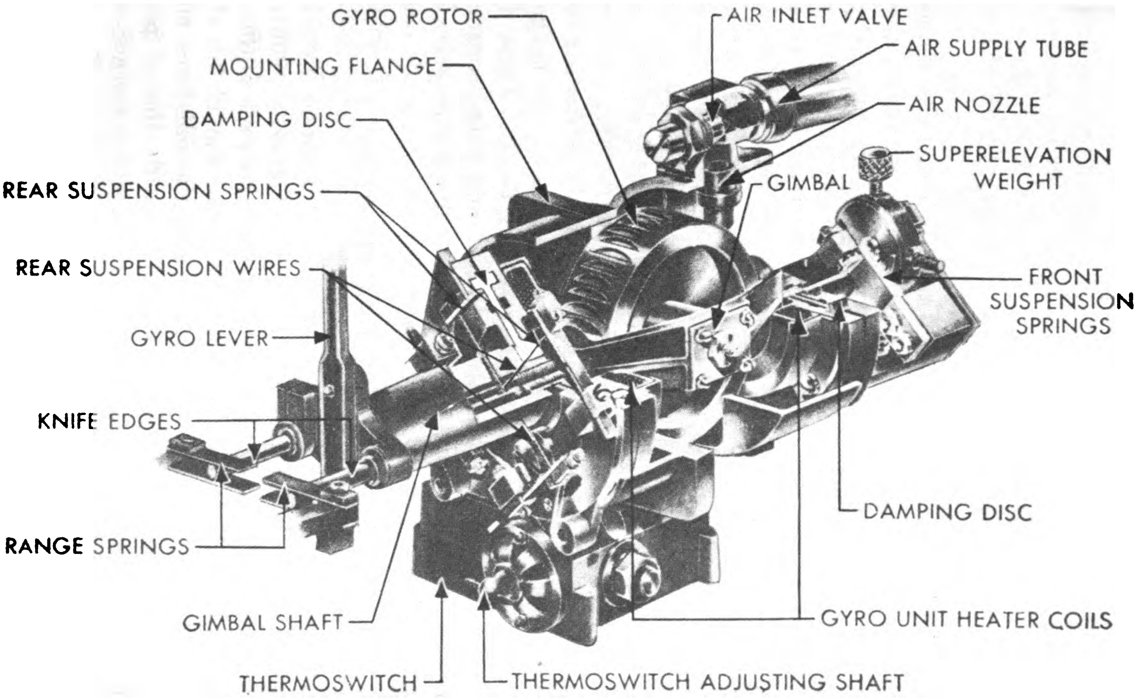


Figure 6–13.—Cutaway view of rate-of-turn gyro showing component parts.

ballistic corrections. Ordinarily, correction should be made to the line of fire for superelevation, wind, drift, initial velocity loss, and atmospheric density. But in the solution of the problem for short ranges, the effect of all but the first is often considered negligible compared to other factors. Some sights, however, correct for wind and drift. Superelevation is the only correction made in the solution of the problem of the sight under discussion.

Superelevation varies with range and elevation. As range increases so does superelevation; with increasing range, the time available for the force of gravity to work upon the projectile is greater and the path of the projectile drops farther toward the earth, thus following a curved line. It is necessary to know the range to the future target position (advance range) before superelevation can be determined accurately. This can be found through a knowledge of range rate, which is defined as the rate of change of range along the line of sight. You learned earlier in this chapter that a negative range rate is always assumed for the sight under discussion, and the range knob dial is properly calibrated to give an approximate value of advance range at the range springs on the output axis of each gyro (fig. 6–10). Thus, if superelevation correction is applied as an additional torque at the output axes of the two gyros, it will be on the basis of the approximate value of advance range.

GUN IN HORIZONTAL POSITION

Superelevation decreases as elevation increases. You'll remember that the amount of the force of gravity which tends to draw the projectile from a straight-line path is that component which works at right angles to the line of fire of the gun. With the line of fire horizontal, the full force of gravity is exerted at right angles. But, when the line of fire is elevated, this component of the total gravity force decreases. As the elevation angle approaches 90° this force becomes smaller and smaller, until finally it becomes zero at 90°. Here the full force of gravity tends only to reduce the velocity of the projectile but not to pull the projectile from a straight-line path.

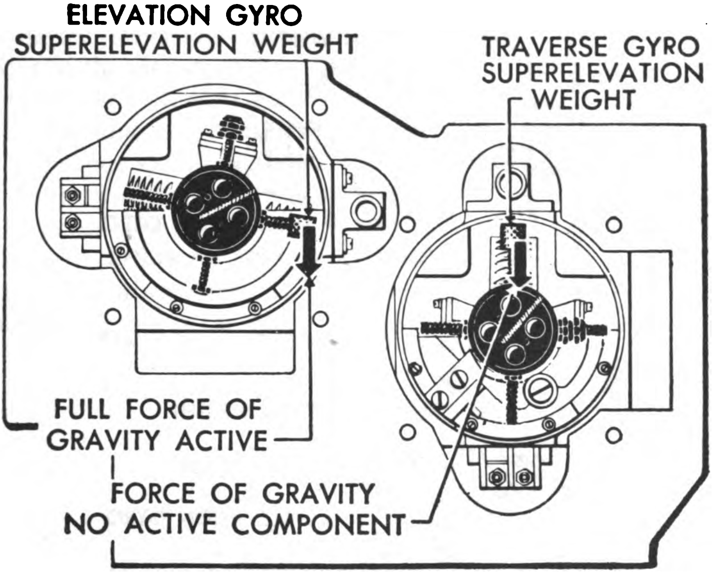


Figure 6–14.—Elevation and traverse superelevation weights.

The superelevation correction is made by the application of a weight at the end of a lever arm on the output axis of each gyro. Figure 6–14 shows these weights as attached to the elevation and traverse gyros. The one on the traverse gyro (right) exerts its weight through the output axis, and therefore has no effect on the angle of precession—while the gun or director is being trained—unless the ship is ROLLING or PITCHING.

With the gun (or director) horizontal as shown, the weight on the elevation gyro (left) has its greatest effect. Of course, its total effect is governed by the setting at the range springs (fig. 6–10). At short ranges the restraint at the range springs is increased and the superelevation weight has less effect on the elevation lead angle. The size of the weight and the length of the lever are adjusted to give correct superelevation correction based on the approximate advance range setting at the range springs.

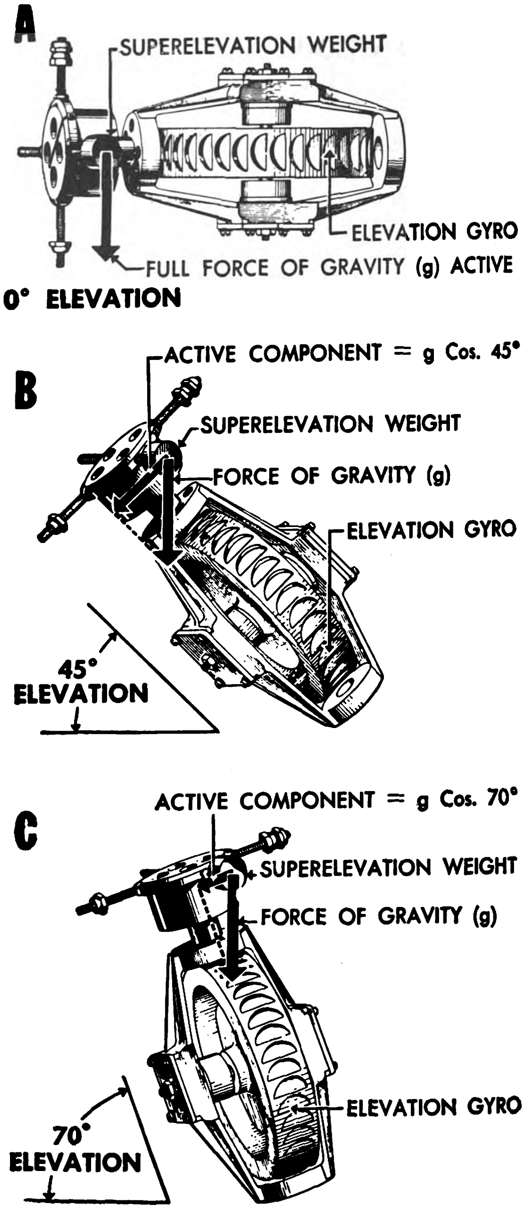


Figure 6–15.—Variation of superelevation correction with elevation.

You can see how the superelevation correction is varied for different elevation angles in figure 6–15. With the output axis of the elevation gyro horizontal, as in figure 6–15A, the gravity force has its greatest effect upon the superelevation weight, and produces a torque about the output axis. As the output axis is elevated with the gun, the component of gravity working upon the weight to cause a tilt of the gyro (that component perpendicular to the arm) becomes less—figure 6–15B and 6–15C—and finally diminishes to zero at 90°. In other words, the force acting on the superelevation weight varies as the cosine of the angle of elevation.

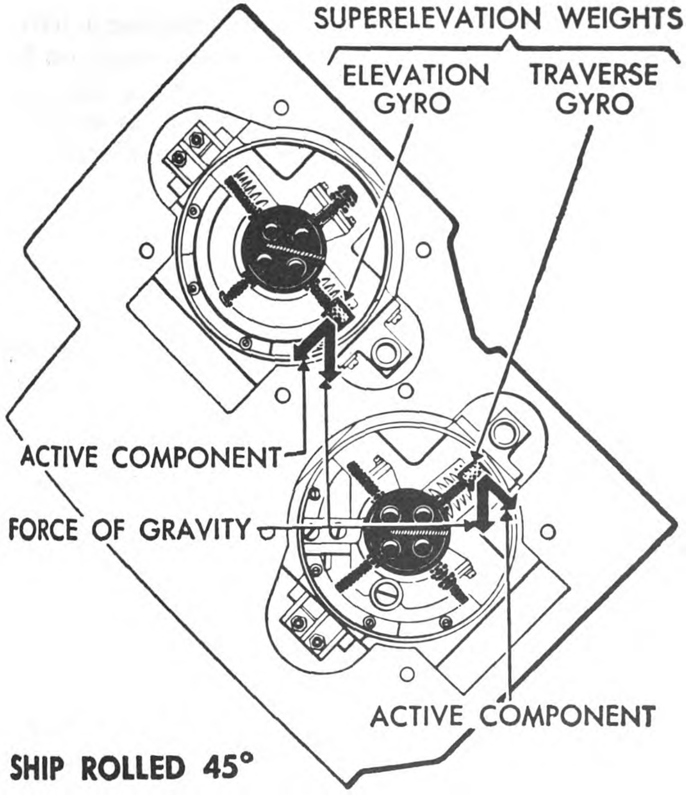


Figure 6–16.—Action of traverse and elevation superelevation weights when the trunnions of the gun are tilted.

Now when studying trunnion tilt, you will find that the gun is carried away from the line of fire in both train (traverse) and elevation whenever the trunnions are tilted. This means the gun must be trained and depressed back to the correct point of aim. Of course the pointer takes care of any change caused by trunnion tilt in the traverse and elevation lead angles by keeping the reticle on target. But in keeping the reticle on target the operator DOES NOT compensate for the trunnion tilt error which arises in the superelevation correction. Superelevation is corrected for trunnion tilt by the combined action of the weights on the output axis of each gyro.

When the sight is tilted as a result of trunnion tilt as shown in figure 6–16, two corrections are present—one in traverse and one in elevation. Take the traverse correction first. Figure 6–14 shows the force of gravity acting ALONG the traverse weight arm with no effect, but as soon as the sight is tilted (fig. 6–16), an active component of gravity acts

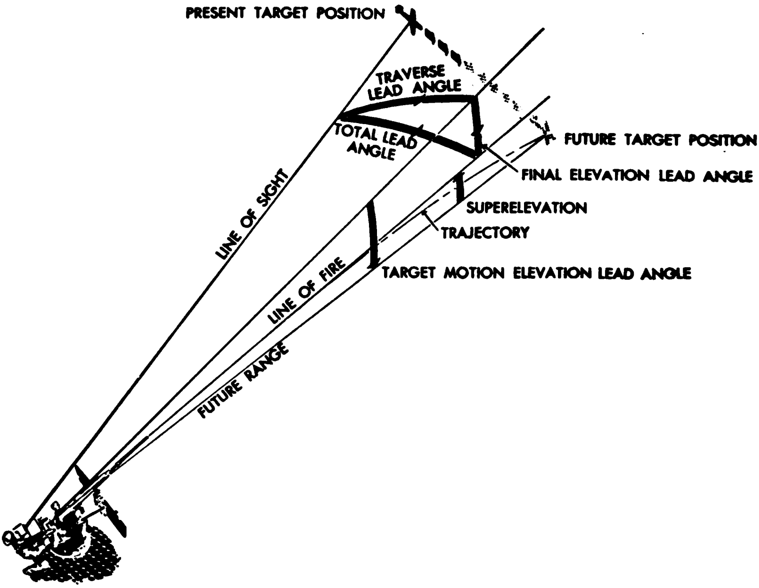


Figure 6–17.—Total lead angles in traverse and elevation.

at RIGHT ANGLES to the weight arm, placing a torque on the traverse gyro output axis. This offsets the reticle and in turn corrects the traverse lead angle to modify, in part, the superelevation correction.

Meanwhile, the effect of the elevation weight DECREASES as a result of the tilt angle (figs. 6–14 and 6–16). The active component of the force of gravity has decreased to cause the correct reduction in torque at the elevation gyro output axis.

In this manner the correct superelevation correction is applied to the output angles of the gyros, regardless of the roll and pitch of the ship.

In figure 6–17 you can get an overall picture of the components of the fire-control problem solved by the lead-computing gun sight discussed here. All elements of the problem are solved by applying torques in the correct amounts to the rate-of-turn gyros.

Damping

The successful operation of lead-computing gun sight depends upon smooth, steady tracking of the target because the lead angle generated by the sight depends upon the rate of turn of the sight in true space. The operator, therefore, must move the sight to exactly duplicate the true relative angular rate of the target.

Various external factors such as lack of coordination, faulty footwork, own ship motion, etc., result in the LOS oscillating around the target. And every time the LOS departs from the true angular rate, the lead angles are false. Moreover, if the operator suddenly jerks the sight to get back on target, the resultant high rate of turn will magnify the tracking error as much as six times.

Thus, it is necessary to smooth out the small, random oscillatory motions of the sight and at the same time leave the sight free to respond to the steady tracking motion that results from the relative motion of own ship and target. This smoothing is obtained by the introduction of damping at the gyros.

Other than the balancing weights and dampers at the mirrors (fig. 6–11), a pair of damping discs are attached to each gimbal axle at each gyro (fig. 6–13). Each disc turns in a closed chamber containing a viscous oil that resists the movement of the disc and, in turn, the gyro gimbal. If the disc is stationary, the damping fluid has no effect. The oil merely rests about the disc. Thus, when a given lead angle is developed, the disc remains stationary and the damping fluid has no effect on the mechanism.

Suppose the rate of tracking changes. Immediately the gyro gimbals will start to turn to a new position corresponding to the new lead angle. But the friction of the oil against the damping discs will resist this movement—slowing down the rate of gimbal tilt. Eventually the gimbal reaches the new position, but it requires several seconds instead of jumping almost instantaneously to the new lead angle.

In this manner the damping discs not only smooth out the random oscillatory motions of the sight, but at the same time introduce a lag into the system. And the lead angle at any instant will be based on the average rate of turn over the past 2 or 3 seconds.

This time lag introduces no error as long as the tracking rate is steady or is oscillating about a steady value. But if the basic tracking rate is increasing or decreasing over a period of time, the generated lead angle will be in error. The lead angle in effect at the instant the gun fires will be based on the larger or smaller tracking rate that existed a second or two earlier. This is often the case, because the bearing and elevation rates gradually increase to maximum as an approaching target reaches crossover.

Now the damper action is such that the faster the lead angle changes the more the damper resists the change. Consequently the error in lead angle would become progressively greater as the plane approached the crossover range. The amount of damping is therefore made dependent upon range in the same manner as the function of time of flight, *Tf*.

Since lead-computing sights are designed for attacking planes, the lag effect of the damping can be overcome by changing the tension in the restraining springs (range springs, fig. 6–10) by an additional amount. If the tension on the springs is less, the gyros can precess farther, and, in effect, overcome part of the lag caused by the damping fluid.

This change in range-spring tension required to offset the lag caused by damping is calibrated as a function of range, and is lumped together at the range-spring input along with the other functions of range. Proper calibration of the range knob dial in figure 6–10 takes care of this matter in the same way that range rate and *Tf* are treated.

Since the damping correction is correct only for a given amount of damping, provision is made to keep the viscous oil at a constant temperature. This is accomplished by employing a pair of electrical heater unit coils (fig. 6–13), which are located inside the gyro housing against the damping-disc chambers. The heat applied to the damping chambers is controlled by adjustable thermostats as shown.

Spotting System

The sight discussed here has two externally mounted spot knobs, one for deflection and the other for elevation. By means of eccentric cams the positioning of the knobs offsets the reticle mask (fig. 6–18). The shaft of each knob goes through a stuffing box provided to maintain tightness against water and air, and terminates in a cam which drives a push rod working against the reticle mask block, as shown. (You can see how the spotting system of figure 6–18 is associated with the rest of the sight mechanism in figure 6–5.)

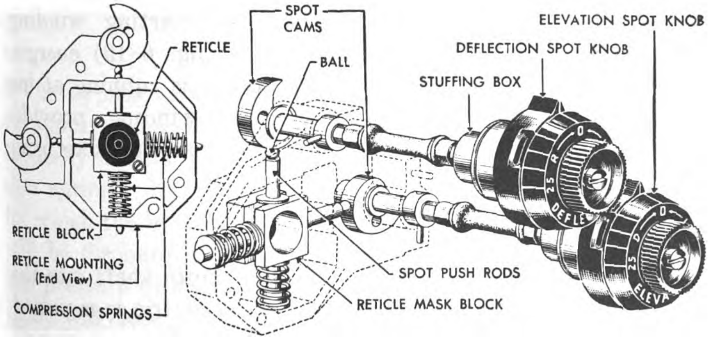


Figure 6–18.—Reticle spotting system.

Two compression springs hold the block firmly against these push rods. Any movement of a spot knob rotates the cam, moving the block against the pressure of the compression springs. Ball detents are provided so that the spot knobs can be rotated in 5-mil increments. This spotting system allows a shift of the reticle image of ±25 mils in either elevation or deflection (traverse).

Air System

The major function of the air power unit shown in figures 6–2 and 6–19 is to supply clean, dry, compressed air for driving the gyro wheels of the gun sight at nearly constant pressure (fig. 6–13). In addition, this unit serves as a central point for all of the sight's electrical power and fuses. The air system drives the gyros at about 9,000 r. p. m.—the gyro speeds vary for different types of sights.

Although the air systems vary with other types of sights, the principles involved are about the same. Thus, a good understanding of this system will greatly assist you in understanding the operation of others.

Air Pump Motor

The air pump is driven by a 115-volt, 60-cycle, $\frac{1}{10}$-hp., split-phase induction motor, of waterproof construction, operating at 1,750 r. p. m.

There are two windings on the motor stator, a running winding for continuous duty, and a starting winding. Centrifugally-operated spring contacts (fig. 6–19) energize the starting winding whenever the motor is running at less than normal speed. This additional winding provides greater torque through an out-of-phase component to bring the motor up to speed.

Eccentric

To convert the rotary motion of the motor shaft into the reciprocating motion of the piston, an eccentric is mounted on the end of the motor shaft (fig. 6–19). The motor shaft extends through a grease-sealed ball bearing into the crankcase of the air pump. A counterbalance attached to the eccentric neutralizes the pounding movement of the off-center mounting of the eccentric. A connecting rod, leading from the piston, is attached to the eccentric by a grease-sealed radial ball bearing.

Diaphragm and Piston

Movement of a rubber diaphragm (fig. 6–19) at the end of the piston admits air into the pump chamber on the down stroke, and compresses the air on the up stroke.

The piston actually pumps no air, but serves as a means of raising and lowering the diaphragm, as well as acting as a mechanical support. The circumference of the rubber diaphragm is firmly mounted in a recess in the head of the air power unit.

Whenever the center of the diaphragm is raised by means of an upward motion of the piston, air is displaced and discharged under 7½ p. s. i. from the pump through the discharge valve (upper right-hand corner fig. 6–19). As the piston and diaphragm are lowered, the discharge valve closes, and air is admitted through the intake valve to complete the cycle (left of the discharge valve in fig. 6–19). The intake and discharge valves are not mechanically actuated, but are controlled automatically by the air pressures created by the movement of the diaphragm.

Bypass Valve

The bypass valve (fig. 6–19) for maintaining a regulated air supply is located in the head of the pump. This valve normally will remain closed under the pressure of a compression spring. If the pump discharge pressure exceeds that for which the bypass valve is set, the valve will open, and air will be discharged to the intake side of the pump. When the pressure drops below the set pressure, the bypass valve again will close. Automatic regulation of discharge pressure is effected by this means. The compression spring may be easily adjusted so that the pressure at which the bypass valve opens can be regulated to about 7 p. s. i.

A pressure gage (fig. 6–19) mounted in the crankcase of the unit indicates the pressure delivered by the pump. When the needle points to the green sector (which represents 6 to 10 p. s. i. above atmosphere), the output is correct.

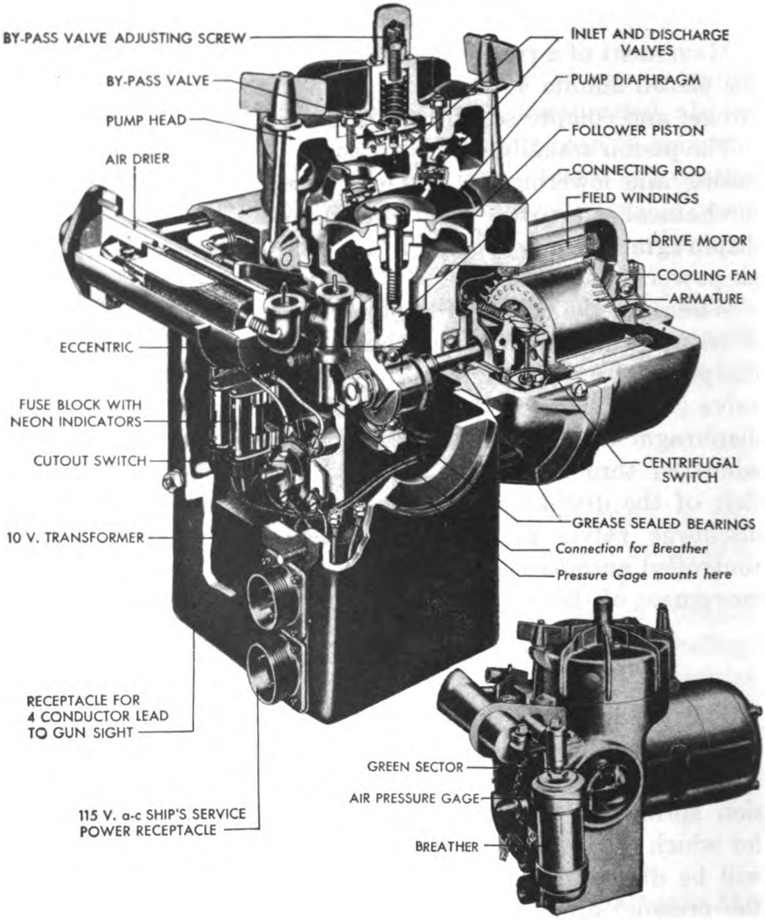


Figure 6–19.—Air power unit cutaway.

Air Drier

From the discharge port in the pump head, air delivered by the action of the diaphragm is piped to the air drier. The air drier (fig. 6–19) consists of a cylindrical housing which contains a wire screen or porous bronze tube filled with an indicator type of silica gel.

Silica gel has the property of absorbing moisture from the air. A chemical indicator has been added to the silica gel in the drier unit so that it has a BRIGHT BLUE color when it is NOT saturated with moisture. When it becomes saturated and loses its absorbing properties, the silica gel becomes PINK in color, and must be replaced or, in an emergency, removed and dried.

Moisture can be removed from silica gel by heating it in a well-ventilated oven at a temperature of 300° F. for approximately 4 hours. When it is activated (completely dried), it regains its original blue color and may again be used in the drier assembly. (Note: When silica gel has been exposed to salt air, it should be washed in fresh water before drying.)

At the end of the drier housing an access cover is held in position against its gasket by two cap screws. Removal of these cap screws allows the cartridge containing the silica gel to be withdrawn from the housing for inspection or replacement.

After passing through the air drier, the air travels to the gun sight through an air hose. (Figs. 6–2 and 6–13.)

Air-Pressure Regulator

An air-pressure regulator (fig. 6–20) is located in the gun sight to eliminate the effects of the air-supply pressure variations. Proper operation of the sight requires that air at a constant pressure be supplied to the gyros to maintain constant gyro rotor speeds.

This pressure regulator has the effect of smoothing out the air supply and operates on a principle similar to the bypass valve previously described. The regulator is adjusted by means of an adjustment screw which varies the tension of the compression spring holding the regulator diaphragm

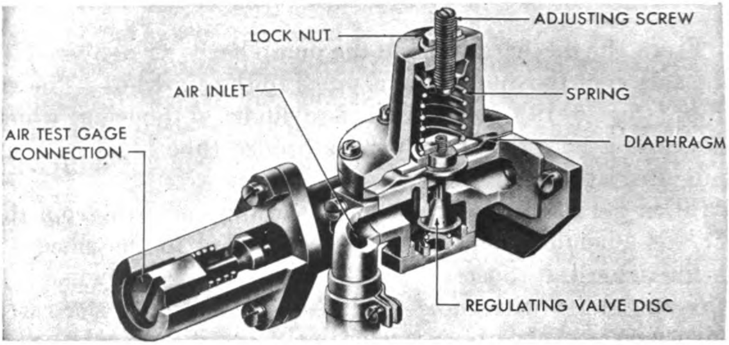


Figure 6–20.—Air-pressure regulator.

in position. It should be adjusted to deliver 2¼ p. s. i. to the gyros. A test gage is furnished for this adjustment.

Intake Breather

An intake breather (fig. 6–19) is installed at the inlet connection to the power unit, permitting air to enter or be exhausted from the system so that approximate atmospheric pressure is maintained in the gun-sight housing. If the breather is not installed, defective operation of the air system might result in the creation of either a partial vacuum or excess pressure in the gun sight. Either would change the operating characteristics of the gyros and, in the case of a partial vacuum, would force harmful salt air into the housing. Like the air drier, the intake breather is filled with an indicating-type silica gel to dry air which may enter the system.

The intake breather, attached near the air inlet to a pipe tee on the intake coupling, consists of a transparent, plastic, cylindrical container which is held in position against a neoprene gasket by a screw cap. The intake breather may be refilled with activated silica gel when necessary.

OPERATION

Now let us see how the principles and devices we have been describing work in an actual Gun Sight—the Mk 14.

Operation of Gun Sight Mk 14 is described in this chapter primarily as an aid to understanding the functioning of the sight. It is not intended to describe or establish any tactical doctrine.

Whenever reference is made to the use of the gun sight on the director, the discussion applies to its use directly on the gun as well, unless otherwise noted. (See figs. 6–1 and 6–2.)

Although the operating procedure discussed here is for a particular gun sight, many of the steps will apply to lead-computing gun sights in general. For specific operating instructions, consult the appropriate OP or OD.

Gun Crew

The gun crew of the 20-mm antiaircraft gun normally consists of three men as follows:

GUNNER. The gunner aims and fires the gun while tracking the target with the gun sight.

RANGE SETTER. The range setter receives or estimates range to the target and sets it on the range knob of the gun sight. He may also make necessary corrections to the range, as determined by observation of the tracer stream, or by other means.

LOADER. The loader changes magazines and keeps the gun loaded.

Gun Director Crew

The crew of the Gun Director Mk 51 Mod 2, on which Gun Sight Mk 14 is installed for the control of power-driven automatic weapons and antiaircraft guns of larger caliber, normally consists of two men, as follows:

DIRECTOR POINTER. The director pointer aims the director by tracking the target through the gun sight, and fires the gun by pressing the firing key on the director handle bar.

RANGE SETTER. The range setter receives or estimates range to the target, and sets it on the range knob of the gun sight. When necessary, he may also make corrections to the range, as determined by observation of the tracer stream or by other means.

Standby Condition

When Gun Sight Mk 14 is secured, the gyro damping fluid is cold and a 30-minute warm-up period is required to bring the fluid to its proper temperature (140° F.) so that the sight can be operated accurately. When on standby, it is essential that the gun sight be capable of operating with full accuracy within a few minutes. To permit this, standby condition may be either of the following:

1. Gun sights without standby wiring must have all electrical connections made and energized, and air hoses connected. The air power unit must be in operation; the gyros must be operating; and gyro unit and air heaters must be energized. The reticle lamp should be off until the sight is to be used. In this condition the sight is continuously ready for instant operation.

2. Where standby wiring is provided, the air power unit is stamped STANDBY. In this case all electrical and air connections are made but only the ship's service supply cable to the power unit is energized, and the power unit switch is turned OFF. The standby wiring within the power unit permits the gyro unit heaters to be energized, keeping the damping fluid at the proper temperature. Before the sight can be used with full accuracy in this condition, it is necessary to turn the power unit switch to ON and then allow about 3 minutes for the gyros to come up to speed.

The connection box from which the ship's service supply connection is fed may be fitted with a switch. If so, this switch must be ON, either to operate the gun sight or to energize standby wiring.

Caution: While on standby, the gun director should be left secured in its normal position, in train and at 0° elevation, with range set at its minimum figure. The 20-mm gun should be secured at 5° elevation.

Preparing For Action

If the sight has been disconnected for securing, the first step in preparing it for action is to connect the 115-volt ship's service supply to the power unit. The junction box from which the current is fed may be provided with a switch. If so, it must be turned to the ON position. Next, the power unit cut-out switch must be turned to the ON position.

The gyro rotors will reach proper speed 3 minutes after the cut-out switch has been turned on, but the damping fluid will not reach proper temperature until the heating units have been in operation for 30 minutes.

In an emergency, it is possible to use the sight 10 minutes after the heaters have been in operation, but it will not give accurate solutions until the full warm-up period of 30 minutes has passed.

In the above it is assumed that the system has not been left in STANDBY condition. If the system is equipped with standby wiring and the power cable has been left connected, the sight may be used with maximum accuracy 3 minutes after the cut-out switch is turned on, this 3 minutes being required for the gyro rotors to reach operating speed.

The conditions of the air hose and electrical connection should be checked and, before tracking with the gun sight, the operation of the following element should be checked:

POWER UNIT PRESSURE. The power unit pressure gage should be inspected to see that the needle points to the green sector of the dial. If it does not, the sight must be checked by a qualified maintenance man.

RETICLE LAMP. Operation of both filaments of the reticle lamp should be checked by turning the reticle dimmer knob to bright position (BR) for each filament and observing reticle brightness in the sight.

NEUTRAL DENSITY FILTER. The movement of the neutral density polarizing filter should be checked by operating the filter lever.

Reticle Movement

After the gyro unit has been allowed to warm up for at least 30 minutes, movement of the reticle should be checked. This is done by swinging the gun rapidly in one direction in train, bringing the reticle to its limit of travel. Then the movement of the gun is stopped and the reticle is observed as it returns to its neutral position. Its movement should be smooth and steady. This test is made in both directions, in train and in elevation. If the reticle appears to move jerkily or irregularly in returning to its neutral position, the sight is faulty and should be replaced. The faulty sight must be returned to a qualified repair station for adjustment.

Cycling

Cycling is the final step taken before placing the sight in operation. Its purpose is to settle the reticle on its true zero position in both directions and to check it for smoothness. Cycling in train can be accomplished immediately after checking reticle movement in train; and cycling in elevation can be accomplished immediately after checking reticle movement in elevation.

Cycling is accomplished in the following manner:

1. Set the range knob at maximum range. Holding the

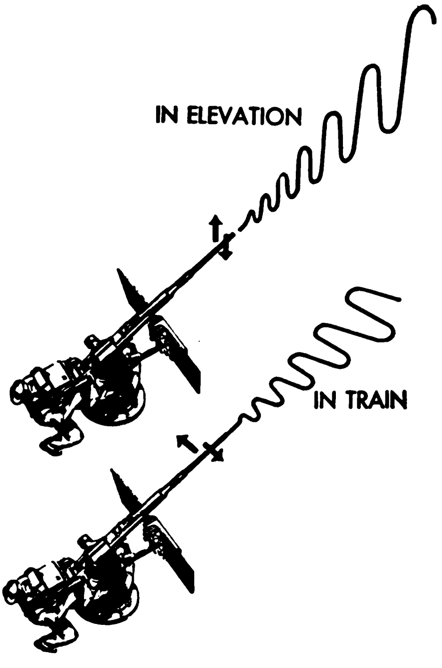


Figure 6–21.—Cycling.

mount in a horizontal position, swing it rapidly from side to side in train (fig. 6–21).

2. Continue swinging the mount, but reduce the speed of swing so that the reticle moves through successively smaller arcs, finally coming to rest. This will be its true zero position in traverse.

3. Holding the mount steady in train, repeat the above procedure in elevation (fig. 6–21), allowing the reticle to settle finally to its true zero position in elevation.

Reticle Brightness

Before actually tracking a target with the sight, it is desirable to adjust the reticle brightness so that, when on the target, any further change to be made will be slight. This is done by adjusting the reticle dimmer knob so that the reticle is visible against the brightest portion of the sky, but not so intense that it will detract from vision. Reticle brightness should be adjusted only if the sight is to be used immediately; otherwise the reticle lamp is left OFF. If necessary to reduce the brightness of the background, the light filter may be shifted into position.

If the reticle is too bright, it will tend to obscure the target and poor tracking will result. If the reticle is too dim, relative to the tracking background, the reticle will be obscured. This also will result in poor tracking.

The Equipment During Action

The preceding paragraphs describe normal procedures for putting the equipment into operation or getting ready for action. The following paragraphs describe the typical procedures for handling the equipment during action, but should be considered as illustrating function and not as advancing specific doctrines of operation.

Slewing

When the gunner first sees the target, he turns the mount rapidly in the target's direction. This rapid swing, called slewing, creates a false lead angle since the rate of swing usually is much greater than it will be after the gunner has begun tracking the target.

Means of correcting, or holding this false lead angle to a minimum, are as follows:

1. The gunner can swing the mount past the target, then bring it back on the target by turning or slewing the gun in the opposite direction (fig. 6–22). If the reverse swing is

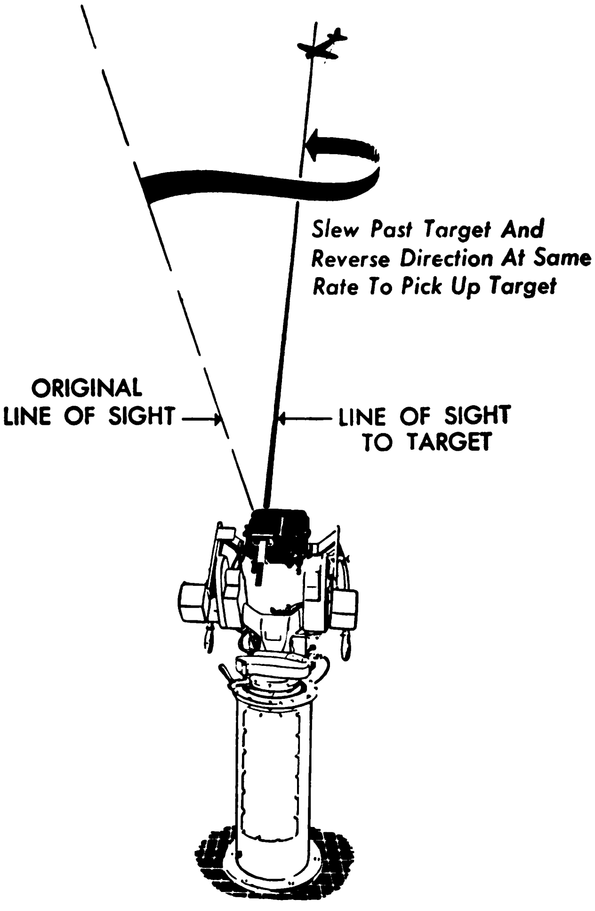


Figure 6–22.—Collapsing lead angle.

made at the same rate as the original swing, the effect will be to collapse the false lead angle.

2. While the gunner is slewing in his attempt to pick up the target, the range knob should be set at its minimum range (400 yards), thus restricting movement of the reticle. The range setter does not set the range until the gunner is on the target.

3. The Gun Sight Mk 14 is equipped with a "caging" device so that the gyros can be held without movement until the gunner is on the target. Caging the gyro nullifies the effect of slewing on the lead angle.

The above paragraphs pertain to the movement of the gun required to bring the sight on the target. Even after accurate tracking has begun and with the gyros uncaged, several seconds must elapse before the gyro units can pick up the exact angular velocity and deliver the correct lead angle. Also the time for the system to adjust to any change in range setting must be considered.

Tracking

It must be emphasized that smooth accurate tracking is the most important factor in obtaining hits when using Gun Sight Mk 14. As demonstrated earlier in this chapter, the correct lead angle depends upon the angular velocity of the target as seen from the gun sight. If the angular rate of motion of the gun is not the same as that of the target, an incorrect lead angle is generated by the sight. Additionally, if tracking is done in a jerky manner, constantly changing lead angles will be generated, none of which will be correct.

The following should be remembered by the gunner or director operator while he is tracking:

1. Keep the reticle dimmed so that it will not obscure the target but can be seen comfortably.

2. If the background behind the target is very brilliant, use the light filter.

3. Concentrate on seeing the target, not on watching the reticle.

4. It is impossible to keep the head in a fixed position

behind the sight. Move the head whenever necessary to keep the reticle in view.

When it is necessary for the trunnion operator to change the height of the gun, he must do so only at times when it will not interfere with the gunner's tracking. He should effect the changes only by immediate or prearranged agreement with the gunner.

Range Setting

Smooth range setting is another factor which will aid the gunner immeasurably in tracking. Any abrupt change in range setting will make a sudden change in reticle position. This may easily throw the gunner off in tracking. Therefore, any change in range during tracking or firing must be made with a smooth motion of the range knob.

In general, there are two methods of applying range settings to the sight. In one the range is purposely set short; in effect, the target flies into the tracer path. After the target has passed through, the range is changed by a previously established amount, and again the target approaches and flies through the tracer path.

In the other method, rather than underset or overset, the range setter attempts to obtain the exact range of target in its present position (by visual estimation, tracer observation, or other means), and sets and adjusts the range control accordingly. To do this accurately the range setter must be thoroughly familiar with the action of the gun sight.

Incoming Target

If the tracers pass ahead (fig. 6–23A) of an approaching target, the lead angle is too great. Assuming accurate tracking, too great a range is set on the sight. If the tracers pass below (fig. 6–23B) or behind the target, the lead angle is too small, and the range setting too low. The first condition requires a definite decrease in range to bring the tracer stream to the target.

The range should be reduced each time the tracer stream appears to pass ahead of the target. Decreasing the range

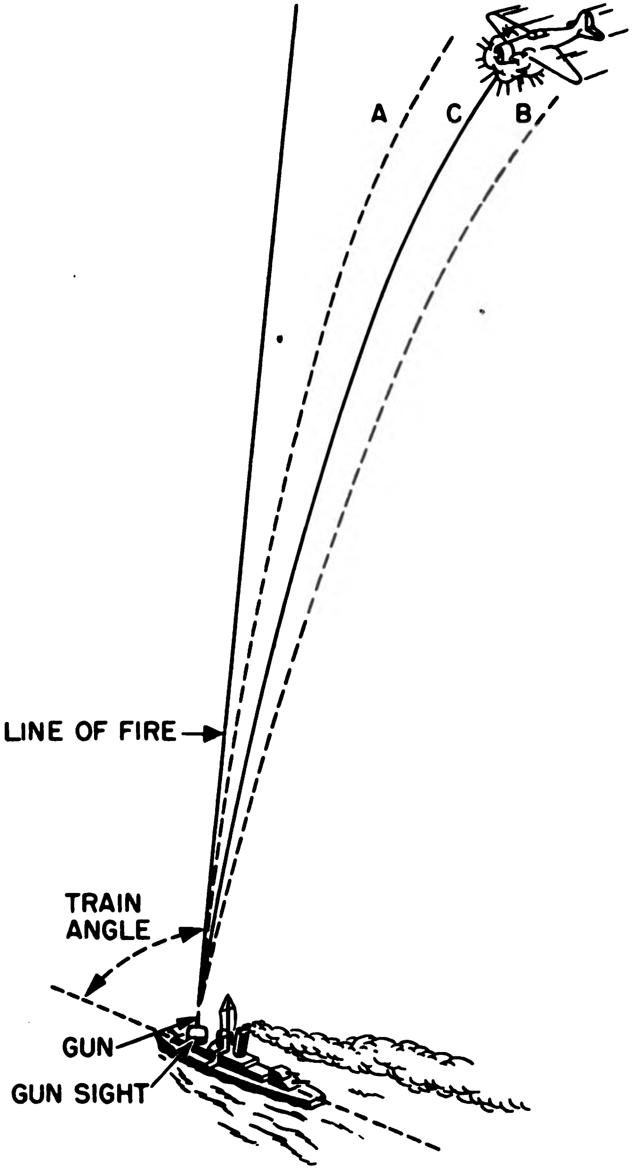


Figure 6–23.—Tracers and incoming target.

too soon causes fire to fall continuously below and behind the target. Conversely, if the range is too great, the fire will fall ahead or above the target, and will not hit an incoming target. The ideal setup for hits is when the tracers appear to be entering the nose of the target. (Accurate tracking is assumed in all cases.) See figure 6–23.

Outgoing Target

With an outgoing target the range is continuously increasing instead of decreasing. In this case, if the range setting is too great the tracers will still pass ahead of the target, but the target will fly into correct range. However, if the tracer stream passes behind and below the target, the range is too short and must be increased to catch up with the target.

Spotting

If the range is properly set on the sight, and if tracking is accomplished smoothly and accurately, the correct lead angle will be generated, and spots will not be necessary. A number of minor errors enter into the flight of the projectile. These include drift of the projectile, wind velocity (which tends to drive the projectile from its normal trajectory), errors in bore-sighting the gun, and errors in the roller path plane of the gun. The normal dispersion of fire of the automatic weapons controlled by the gun sight should be larger than the total of all these errors. Therefore, spotting to correct such errors is unnecessary, and can be harmful.

The range setter should avoid applying spots while the gunner is firing, since applying spots causes sudden movement of the reticle, and may throw the gunner off the target. For the same reason it has already been pointed out that the range must be changed smoothly. Spots should seldom be applied and then only to correct for a known consistent error.

Securing

The gun sight should be secured in the following manner:

1. Shift range knob to minimum range (400 yards).

2. Bring gun mount or director to secured position in train, and lock.

3. Bring gun mount to 5° elevation, and insert locking pin. (Gun director is locked at 0°.) Release elevation locking pin from its top, and move gun slowly at low elevation until pin slides into place.

4. If standby wiring is not provided, and gun is not to be left in a "ready" condition, turn power unit cut-off switch OFF.

5. Disconnect 115-volt ship's service power supply only if so ordered.

Caution: It is important to secure the sight in an approximately horizontal position, to allow the damping fluid in the gyros to settle in the proper position. The action of the gyros would be faulty and incorrect lead angles would be generated if the fluid were to settle incorrectly.

If the sight is inadvertently left in a highly elevated position, the following should be done before placing it in service:

Bring sight to a horizontal position and allow it to warm up from two to three hours. Then check the performance of the sight by making the following performance tests: dead zero test, range shift test, characteristic time test, and deflection (sensitivity) test. When these tests show the sight to be operating satisfactorily, it is ready for service. (These tests are described in the OP on the gear.)

Notes And Safety Precautions

The following safety precautions and notes relating to operation of Gun Sight Mk 14 are listed here for summary purposes.

1. If standby wiring is provided and is in use, allow 3 minutes for gyros to reach proper speed.

2. Whenever the sight is not actually in use, it must be kept in an approximately horizontal position (0° for director, 5° for 20-mm mount).

3. If air pressure from the power unit is not correct, or if reticle movement is uneven, use the sight only in an

emergency. Have the sight checked by a maintenance man at the earliest opportunity.

4. Always cycle the sight in train and elevation before placing it in use.

5. When slewing, always set the range knob at its minimum setting (unless gyros are caged).

6. When slewing at a high rate, it is recommended that target be picked up by "overshooting" (unless gyros are caged).

7. If a caging device is installed, always cage the gyros when slewing.

8. Never change trunnion height when firing, and only change it carefully when tracking.

9. Always make changes in the range setting with a smooth motion of the range knob.

10. Never reduce range on an incoming target until the tracer stream appears to pass ahead of the target.

11. Never increase range on an outgoing target until the tracer stream appears to fall behind the target.

12. Apply spots only when necessary. If undecided, do not spot.

13. When firing has ceased and gunner is searching for another target, immediately set range at minimum (400 yards).

14. Always secure gun mount at 5° elevation (gun director at 0°) with range set at 400 yards.

15. If gun has inadvertently been secured vertically, have performance tests made before placing sight back in operation.

16. If standby is NOT provided and sight is to be used again within 30 minutes, leave power unit cut-out switch ON. If standby wiring is provided, cut-out switch can be turned OFF.

QUIZ

Fill in the word or words which BEST answer the question or complete the statement.

1. The simplest types of lead-computing gun sights can compute the entire short-range fire-control problem with the single input of __________.
2. The rate-of-turn gyro will precess until the pull of the crossarm is exactly __________ by the tension of the restraining springs.
3. The rate-of-turn gyro will remain in the precessed position as long as you continue to rotate the case at the same __________.
4. The traverse lead angle is measured in a plane containing the LOS and the __________ axis of the gun.
5. The gyro system positions a pair of mirrors so that the line of sight __________ the line of fire in elevation and traverse.
6. The purpose of the optical system in the lead-computing sight is to superimpose the __________ onto the pointer's field of view.
7. Tilting the __________ mirror causes the reticle image to move from side to side, whereas the tilting of the __________ mirror causes the reticle to move up and down.
8. The tilt of rate-of-turn gyro is __________ proportional to the stiffness of the restraining springs.
9. The approximate value of advance range (and in turn, *Tf*) is put into the sight by properly calibrating the __________ dial.
10. Advance range is calibrated in terms of present range with the assumption that range rate is __________.
11. The mirrors and lever systems __________ the lead angle measured by the rate-of-turn gyros.
12. The superelevation correction is made by the application of a __________ at the end of a lever arm on the __________ of each gyro.
13. The only time the traverse gyro superelevation weight has any effect is when the deck is __________.
14. The elevation gyro superelevation weight has __________ effect when the gun is elevated to 90°.
15. The pointer takes care of any change caused by __________ tilt in the traverse and elevation lead angles by keeping the __________ on target.
16. Whenever the trunnions are tilted, the effectiveness of the elevation gyro superelevation weight is always
    - a. increased
    - b. decreased
    - c. counterbalanced
    - d. zero

17. The time lay caused by the damping discs introduces no error as long as the tracking rate is
    a. steady
    b. varying
    c. deviating
    d. unsteady

18. The change in range spring tension required to offset the lag caused by damping is calibrated as a function of
    a. elevation
    b. train
    c. range
    d. parallax

19. Spots in deflection and elevation are introduced by offsetting the
    a. superelevation weight
    b. reticle block
    c. air dryer
    d. reticle lamp

20. The purpose of the air power unit is to supply clean, dry, compressed air for driving the
    a. gyro wheels
    b. range units
    c. damping discs
    d. traverse mirrors

21. The air pressure regulator of the Mk 14 gun sight is adjusted to deliver a constant pressure to the gyros of
    a. 3 p. s. i.
    b. 2¼ p. s. i.
    c. 3¼ p. s. i.
    d. 4 p. s. i.

22. When silica gel has been exposed to salt air, in which of the following should it be washed before being dryed by baking?
    a. Salt water
    b. Fresh water
    c. Acetic acid
    d. Citric acid

CHAPTER 7

MAINTAINING F-C CIRCUITS

To the average layman the wiring of fire-control electric circuits aboard ship looks like an endless conglomeration which only a genius could contrive. But to the experienced Fire Control Technician, it is a compact, orderly, and neatly assembled group of component circuits. Each wire and each part plays a particular role in making the fire-control system work as a whole, and the failure of a single component can mean complete failure of the system. Therefore, through long experience, the Navy has devised maintenance methods of the highest standards. The Navy's main secret of success in the maintenance fields has been, and always will be—WELL TRAINED TECHNICIANS. See figure 7–1. The Navy keeps these skilled men well informed with up-to-date drawings, test procedures for the circuits aboard ship, lubrication charts, and operating instructions for every single machine. Moreover, the naval technician is well equipped with precision test instruments. The only way you can fit into this organization is to develop and improve your own abilities. Through study and experience you can become proficient at electrical maintenance as well as at the many other requirements for a Fire Control Technician.

This chapter will give you some of the principles which will head you in the right direction; more will follow in later courses. However, before you start this chapter you are expected to have studied the Navy Training Courses in *Electricity* and *Electronics*. If you haven't copies, you can get them from your division or training officer.

Material Maintenance

Just as important as the operation of ordnance equipment is the proper maintenance of that equipment, so that it will be serviceable when needed. Modern ordnance equipment is complex and requires constant checking, testing, lubrication, and adjustment to keep it in first-class operating condition. Much of this routine, day-to-day, week-to-week work can be called "preventive maintenance."

PREVENTIVE MAINTENANCE means taking care of equipment in such a manner that the need for actual "trouble shooting" is minimized. It may not be possible to prevent all casualties to your equipment, but most of the "out-of-operation" time can be eliminated by a systematic preventive

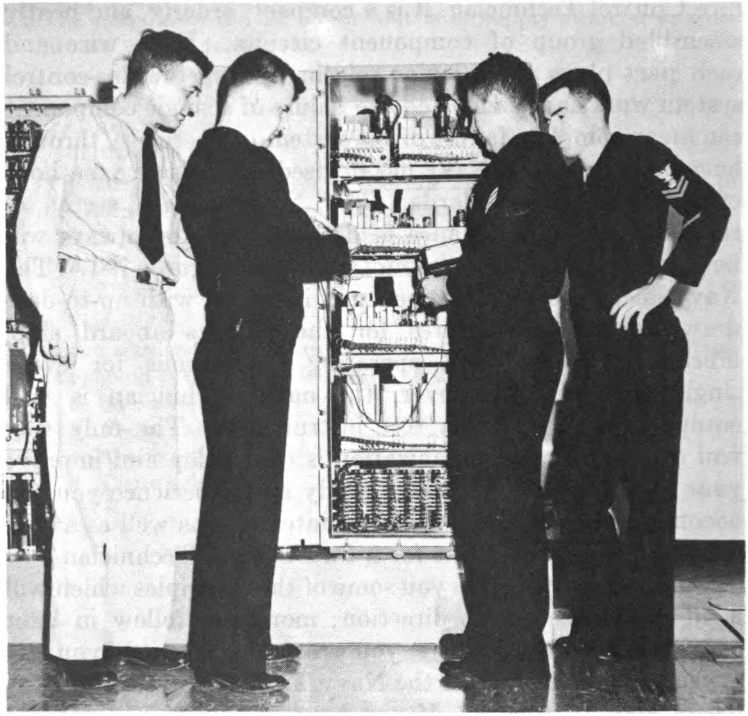


Figure 7-1.—Trouble shooting on a MK 35 power drive amplifier panel at FT School.

maintenance program. To carry out this program requires that you know your equipment. The program will require time, but it requires less time to prevent a casualty than to correct it if it is allowed to occur.

Without preventive maintenance, equipment casualties may pile up to the extent that an FT is lost in confusing indications of several component failures. With preventive maintenance the equipment is ready for operation when it is needed.

Radar Casualties

Casualties to radar equipment will be of two types: those to electrical circuits and those to mechanical moving parts. Preventive maintenance will have as its purpose the prevention of both these types of casualties.

All casualties that can be prevented by preventive maintenance will be indicated by symptoms that can be detected by maintenance personnel. A good visual inspection of the equipment will reveal signs of possible trouble. It may be a frayed wire that could be a potential short, a loose switch, or a loose tube clamp. Take care of these little problems immediately.

An operational check will tell much more about the operating condition of the equipment. There are many ways by which symptoms of trouble may be detected. The indicator presentations provide an indication of how the equipment is operating. Target acquisition and automatic tracking tell the story of equipment performance. If the equipment doesn't perform as it should, preventive or corrective maintenance is necessary. An operational check will include reading of all meters. When these readings deviate from normal, as prescribed by the operating instructions on the equipment, an investigation of the cause is a maintenance problem.

Regular performance of the standardized adjustments to the radar equipment is an extremely effective preventive maintenance procedure. For further information on this see the OP on your radar.

There are many examples of how routine adjustments will reveal that a circuit is not operating at peak performance.

If a tube replacement does not obtain peak performance, then further checking in the particular circuit should reveal the faulty component. Find and replace the faulty part before it takes your equipment out of operation. Preventive maintenance should be performed at a suitable time when the circuits can be clearly analyzed. Too often the lack of preventive maintenance results in a need for corrective maintenance at a time when the equipment is needed for operation, and the emphasis on getting it into operation may lead to hasty circuit analysis and additional loss of time.

Circuit Casualties

Casualties to electrical circuits will consist mainly of tube casualties. Preventive maintenance requires that these casualties be anticipated and that tubes be replaced before a casualty occurs. Several methods will be useful in anticipating tube failures. An "hours-of-service" record will soon establish the normal life expectancy of a tube in a particular circuit. Close attention to meter readings, position of adjustment controls, indicator presentations, and operating performance of the equipment will indicate that tubes may be deteriorating. Systematic checking of tubes is an aid in anticipating tube failures.

Any tube-checking program for radar equipment, in order to be successful, must be based on the assumption that a tube that checks good in one circuit may not work as well in another circuit. This means that when you check a tube from its socket and find that it is good, return the tube to the same socket. It might not perform satisfactorily in any other circuit in which that same tube is used. Readjustment of the circuit would be necessary if that tube is placed in a socket other than the one from which it was removed. Wholesale removal of tubes for tube checking is not recommended.

It is well to keep in mind that tubes deteriorate on the shelf. Accumulation of gas within the tube envelope may make a tube useless as a repair part.

Mechanical Casualties

Radar equipment is more than vacuum tubes and electronic circuits. Its operation depends upon a number of moving mechanical parts. Many of these mechanical parts require lubrication at regular intervals. The OP for your radar gives the lubrication information. If these lubrication charts are used, your equipment will perform more effectively. Lubrication is important, do not neglect it. Avoid over-lubrication as it often is as damaging as under-lubrication.

Another important part of preventive maintenance is adequate ventilation of the units that must dissipate considerable heat. Blowers have been provided in these units for ventilation. Make sure the blowers are operating and that the air vents are not obstructed.

Systematic Program

Preventive maintenance takes time. But a digest of service reports received by the Bureau of Ordnance on fire-control radar equipments points out the effectiveness of a preventive maintenance program, so the time is well-spent. Unfortunately, this program is not carried out on all installations. As a result, many equipments are not operating at peak performance.

A systematic preventive maintenance program will:

1. Maintain electronic equipment at designed standards of performance.
2. Cut corrective maintenance manhours by eliminating minor troubles before they become too serious.
3. Create familiarity with the electronic equipment which will lead to quick and effective corrective maintenance.

NOT FOOL-PROOF

A good preventive maintenance program will not eliminate all casualties. Some breakdowns will occur and only systematic corrective maintenance will return the equipment to full operation. It is essential that the technician be prepared to cope with many kinds of equipment casualties.

The first requirement for corrective maintenance is knowing the equipment. Knowledge gives confidence. One casualty repaired makes the next casualty look easier. Knowledge, confidence, and experience blended into a system will solve all corrective maintenance problems.

Corrective maintenance will require test equipment, tools, and replacement parts. Test equipment should be adequate and stowed in an easily accessible location. A full allowance of tools should be readily available.

A number of frequently used repair parts, such as tubes and fuses, should be in bin stowage in the radar room. Being prepared for an emergency makes the emergency less serious.

Localize Casualty

When a casualty occurs, it must first be localized. Probably it is a tube but there are several hundred of them in radar equipment and a "hit or miss" method of locating the defective one is time consuming. Observe what the symptoms are. If the equipment can be energized to OPERATE, do this and look at the indicators and at the meters. From the symptoms available you will have a starting point.

Tube Casualties

Tube casualties may be low emission, open filaments' shorted elements, gassy tube and miscellaneous casualties of less frequent occurrence. Good preventive maintenance will eliminate most of the low emission type of tube failures. Shorted elements and gassy tubes, however, may cause failures of other components in the associated circuit.

Tube casualties can be located by using the Servicing Block Diagrams, waveforms at the test points, and a tube checker, or the substitution of a known good tube. Resistor casualties will require that test point information, or indicator presentations, be followed by voltage or resistance checks in the stage in which the trouble has been localized. Voltage and resistance data for each tube pin will be found in the OP's. Location of a failure, such as an open circuit in the interunit wiring, will require that you refer to the Interconnecting Wiring Diagrams. This type of trouble may occur within the cable twist to the Mark 37 Director. It will be necessary to pick up a spare lead in the particular cable, or replace the cable, after the open lead has been located definitely.

Resistor Casualties

Casualties in resistors are mainly of two types: change in value or the resistor burns out. Both of these failures may be due to failure of an associated part or to maladjustment of the circuits. These failures will produce different symptoms. An open or shorted resistor may result in the equipment being inoperative, while a resistor that has changed in value may result in circuit adjustments being unattainable or incorrect performance of the circuit. A survey of component failure reports over several months shows that casualties in resistors may exceed 5 percent of the total number of casualties. The remaining casualties will be distributed throughout other components of the equipment. Each one will present a particular problem. Finding the failed component will be accomplished by the same method: observe the symptoms, use the maintenance information available in the OP's, and make the necessary tests and measurements until the defective component has been located.

Maintenance Notes

The OD's on Fire Control Radar Maintenance Notes will be particularly helpful to you and are available aboard ship. The information contained in these publications is kept up to date by frequent changes. A maintenance note will "point a finger" at a trouble which occurs commonly. It may be one that will occur to your equipment. Read these maintenance notes and be prepared. Refer to the notes if you encounter a particularly complex problem. Some other technician may have encountered this trouble, and if so, the solution is there for you.

Know Your Equipment

Let us repeat—knowing your equipment is your most effective tool for solution of corrective maintenance problems.

To know the flow of information going through the equipment will help immensely in determining what additional symptoms can be obtained from changing positions of switches. More symptoms will mean that the trouble location can be narrowed to a smaller part of the equipment. Localizing the trouble is your first step in casualty analysis.

Maintenance information available in the OP will help to further localize the trouble. Using this information will be your next step.

Making effective use of the available test equipment to locate the faulty component is the third step. In most cases the Test Oscilloscope and a good Vacuum Tube Volt-Meter (VTVM) will be all that are necessary. Some corrective maintenance problems may require an external oscilloscope, while others may require such test equipment as the TS–147 (Radar Test Set) and the TS–148 (Spectrum Analyzer). However, with the Test Oscilloscope and a good VTVM, most troubles can be located.

Troubles may occur in any functional system of the equipment, and in many cases the symptoms may be visible in another functional system of the equipment as well. Power supply casualties may first become evident in the Indicating System. Failure of a tube in the Synchronizing System probably would be first evident in the Indicating System. Blown fuses may be caused by component failure in any of the functional systems.

Available Repair Parts

Finding the failed component in your radar equipment may be time consuming, and often it is just as time consuming to obtain the specified replacement part. Usually it requires only a few minutes to install the part when it has been obtained. It is no small task to make sure that the required repair parts are aboard ship, and can be found readily when the need for them exists. The fact that a replacement part is available is the result of cooperation all along the line, from the manufacturer, the Bureau, ESO, on down to the supply organization aboard a particular ship and the technicians who will be using the parts. Become familiar with the supply organization aboard your ship and your responsibility in helping to keep stock of adequate repair parts.

Obtaining Parts

Let us assume that you have had a casualty in your radar equipment and have found that a resistor in the B+ lead to the Video Amplifiers in the Video Amplifier Chassis has burned out. On the schematic you will find that the resistor is designated as R12, 220 ohms. The 220 tells you only the resistance value. There will be a large number of 220-ohm resistors carried in the Shipboard Integrated Electronic Maintenance Parts System. They may be different in composition, different in size, different in wattage rating, and different in tolerance because of the different shipboard equipments in which a 220-ohm resistor is used. To requisition your replacement part you will need a number to identify the part. To obtain this number you will refer to the SNIT (Stock Number Identification Table) list for your radar equipment.

Two copies of the SNIT list are provided for each equipment. One copy is to be kept with the instruction book for the equipment—the other is retained in the supply organization.

The SNIT list is arranged in both alphabetical and numerical orders of the part, the unit number in which the part is located, and the schematic number of the part. You will locate the part designation and find there are two stock numbers listed for it. Both are Standard Navy Stock Numbers (SNSN), one being the Replacement Stock Number and the other the Equipment Stock Number. In many cases these numbers are identical. Always use the Replacement Stock Number in your first attempt to obtain the replacement. This part will be as good, or better, than the part identified by the Equipment Stock Number. If this part is not in stock, then try the Equipment Stock Number. In rare cases the part may not be obtainable under either stock number.

It is your responsibility to keep the equipment in operating condition. If the needed part is not available aboard your ship, it can be obtained from a tender, shore base, or, in an emergency, from other ships in the area. Explore all possibilities to obtain the desired replacement part—and remember—if you have done your part in keeping up the stock on your ship, you'll likely be able to procure it there.

ELECTRICAL WORK

There isn't much about the basics of electrical work that hasn't already been covered in the basic Navy Training Courses mentioned earlier in this chapter. If you haven't already done so, you'd better get a copy of the Basic Electricity book and review the sections on electrical wiring technique. Also, you can learn a lot about reading fire-control electrical diagrams and servicing such devices as servo motors, synchro units, rotary switches, etc., in *Basic Fire Control Mechanisms Maintenance*, OP 1140–A.

There are, however, a few things you'll need to know concerning electrical work which are not covered in these books and which therefore will be briefly discussed in this section.

Watertight Boxes and Fittings

Aside from mechanical injury, the biggest source of electrical trouble on board ship is moisture. And salt water moisture is the worst kind because it is a conductor of electricity. Thus, when a cable or box becomes saturated with salt water, two things happen: first, a current path to the ship's hull is formed which is a ground, and second, especially where dissimilar metals are involved, electrolysis and corrosion occur and the connections or wire fittings are slowly eaten away. Therefore, practically all of the electrical wiring aboard ship is run in waterproof, fire-resistant, armored cables which terminate in watertight boxes.

The cables are run into boxes through stuffing tubes, also called terminal tubes. When renewing cable these tubes must be repacked with a standard packing corresponding to the size of tube, and the packing ring and nut must be tightly secured. Figure 7–2 shows a cross-sectional diagram of a stuffing tube properly assembled with an armored cable

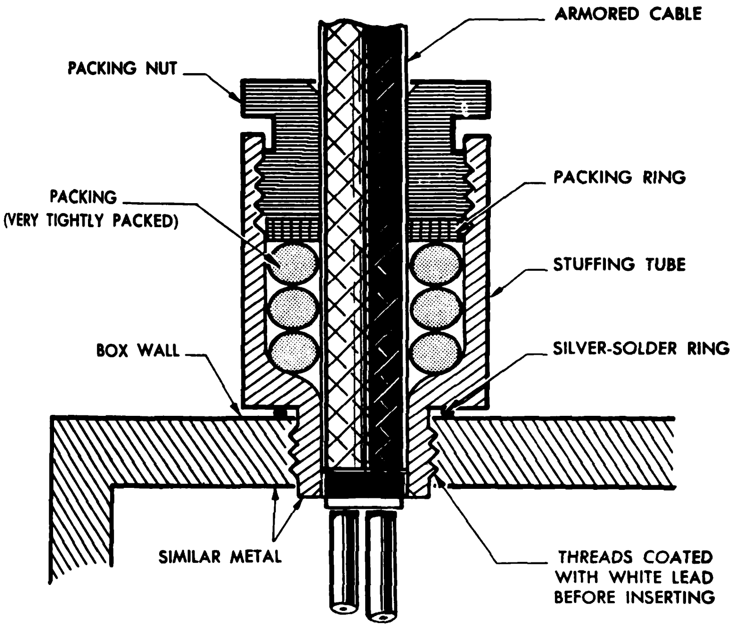


Figure 7–2.—Watertight stuffing tube.

in place. Stuffing tubes similar to the one shown are used to insure watertight integrity where cables pass through decks and bulkheads. Where cables pass through the deck, pipe risers are used in order to prevent mechanical injury to the cable. The stuffing tube is then inserted at the top of the pipe.

Terminal and junction boxes used for most fire-control work are rated according to the number of terminals they contain, for example, 10-wire box, or 50-wire box. All wires are lugged at the ends to insure soled connections at the terminal strips or blocks within each box. The lugs are or should be stamped with circuit designation numbers to assist the maintenance man in tracing out circuits. You'll find the cable leads laced together with cord and neatly arranged in each box to make for compactness and ruggedness. Always rearrange the box in this manner after pulling out leads for inspection, making tests, or relugging. Always make certain that the gasket of the box cover and the cover are in place and that the cover is bolted down securely before leaving the box.

Summing up: whenever renewing wiring, every effort should be made to make solid connections and watertightness at all boxes and cable fittings. Also, all wiring should be arranged to be as free from mechanical injury as possible. Always replace cable with the exact replacement part or as specified by the gunnery officer.

Electrical Trouble

It would be almost impossible to list all of the electrical troubles that might occur in electric wiring installations. However, as you may know, most electrical troubles come under the headings of shorts, opens, and grounds.

Shorts and grounds are closely related in that two grounds, one on each side of a line, cause a short circuit. Even partial grounds can give trouble as they may cause excessive current in the wires. In order to detect grounds before they become serious, daily ground tests are taken from the fire-control switchboard with a megger. The megger, as you probably know from your study of Basic Electricity, is a special ohmmeter for measuring insulation resistance. Some circuits have an intentional ground at the switchboard; this ground can be removed by opening a switch while taking ground tests. The more important ground tests are listed in the chart which follows.

Ground Test Chart

Every effort must be made to keep the insulation resistance of all fire-control circuits high. Low resistance readings on insulation indicate potential sources of electrical failures. The following tests will give you an idea of what these readings should be; the readings indicate the minimum considered satisfactory when taken with a 500-volt megger.

It is a fairly easy task to locate a ground in a cable or circuit. The first step is to deenergize the circuit at the switchboard, get a megger, and go to the junction box.

Type of Circuit	*Insulation Resistance Reading*
Circuit wiring with all wiring and appliances connected but instruments disconnected.	5 megohms.
Circuit complete with instruments connected	⅕ megohm.
Motor and generator circuits with motor or generator and control appliances disconnected.	5 megohms.
Motor and generator circuits with motor or generator and control appliances connected.	⅕ megohm.
Instruments, measuring and indicating, such as voltmeters, ammeters, wattmeters; and electrical audible signals such as bells, buzzers, horns, sirens, fire-control instruments, contact makers, transformers and relays.	5 megohms.
Local circuit wiring on switchboards	⅕ megohm.

Then open the box, disconnect the grounded cable leads, and test each lead entering and leaving the box. Perform a thorough test and inspection to find the exact location of the ground. The ground most likely will be caused by moisture. If not, it will be found that the ground is caused by a mechanical injury or some defect.

An open circuit means the wire is broken or corroded in two, or a contact or fuse is defective. Broken wires in cable twists at directors, turrets, and guns are often sources of opens. Dirty contacts at slip rings and similar devices are other possible sources of trouble.

When you test a circuit for opens, you test it for continuity. Once the fuses have been tested the next step is to test the circuit itself. This is done by going to a junction box and disconnecting the leads of the cable entering and leaving the box, and testing with a circuit tester or megger. All tests are made with the circuit deenergized. After you've found out which leg of circuit is open you go to where the circuit is terminated and test as before. One method of testing is shown in figure 7–3. This is a handy method when you have no one to assist you. One lead is tested at a time, the return circuit being through the ship or ground.

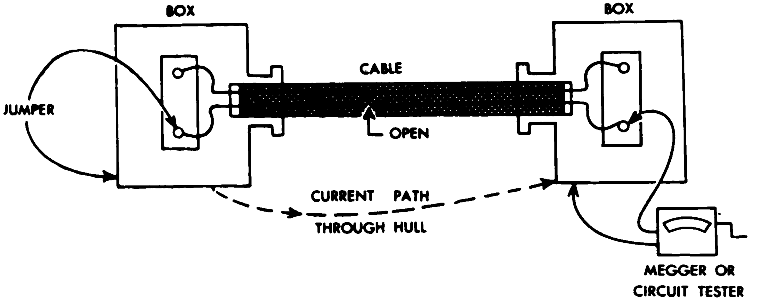


Figure 7–3.—Testing for an open circuit.

You simply connect the lead under test ground with a jumper and then test for a complete circuit through the suspected wire from other points along the line.

Another method which may prove to be much quicker is to talk out the leads one at a time with sound-powered telephone handsets. Here again it is always handy to use the ship hull as common. Of course this method requires two persons.

Table of Common Faults

The following table of common circuit faults should prove of great value to you in learning to trouble-shoot the electrical circuits from plotting room to topside equipment, for the troubles enumerated here are the ones that you will most often meet.

Locating and Correcting Grounds

Signs	Causes	Correction and Repair
Low insulation resistance on ground test.	Water in switch and receptacle box; damaged insulation; bare or exposed conductor.	Remove water, dry and coat with insulating compound; repair conductor.
Do	Corrosion from chemical action.	Remove corrosion and make apparatus tight in order to exclude salt air and water.

Signs	Causes	Correction and Repair
Low insulation resistance on ground test.	Defective portable material.	Remove and repair electrical material.
Do	Improper and insufficient insulation.	Reinsulate and coat with insulating compound.
Do	Deterioration of insulation due to oil or grease.	Remove damaged section, replace with new if necessary.
Do	Surface ground from accumulation of moisture and dirt or dust.	Clean and dry thoroughly.
Do	Hole drilled through deck above into cable, making partial contact to conductor.	Repair cable, reinsulate or replace as necessary.
Do	Deterioration of rubber due to oxidation.	Reinsulate or renew wire as necessary.
Do	Insulation injured or chafed due to vibration.	Reinsulate or renew wire and secure it from vibration.
Fuse blown	Water in junction box, rubber gasket damaged.	Remove water, dry out junction box, correct source of leak.
Do	Water in switch and receptacle box; stuffing tube improperly packed.	Dry out inside of switch and receptacle box; repack stuffing tube, make watertight.
Do	Connections become loose causing short in box.	Repair connection and secure properly to prevent recurrence.
Do	Broken lamp, filament short-circuited.	Remove lamp, replace with new lamp.
Do	Connections pulled loose shorting connections.	Secure cable and repair loose connections.
Do	Portable appliance short-circuited.	Remove and repair portable appliance.

Signs	Causes	Correction and Repair
No Illumination on Indicator Regulator, fuse O. K.	Broken connection inside switch and receptacle box.	Repair broken connection.
Do..........	Corroded connection making open circuit.	Repair corroded connection and clean the interior.
Do..........	Connections pulled loose from cable.	Secure cable and repair connections.
Do..........	Portable appliance defective.	Remove and repair defective portable appliance.

Multiple Conductor Cable—Circuit Designation

Thus far trouble shooting appears to be a snap, but when you think of working in and out of boxes with as many as 200 wires in them, it's a different story. However, if you know circuit designation and color codes, along with the testing methods previously discussed, the task is much easier.

In order to make multiple conductor circuits easier to trace, fire-control circuits, like I. C. circuits, are designated by a system of letters and numbers. The designation markings are placed on the wires or lugs at all junction and terminal boxes, switches at switchboards, etc., and on metal tags secured to the cables wherever they pass through a compartment or deck.

It is the practice in the Navy to adhere as closely as the varied installations on different ships will permit to identical numbers or similar main subdivisions of fire-control circuit numbers and letters. This enables the Fire Control Technician to become thoroughly familiar with circuit designations, and to identify at a glance the wiring of a particular fire-control circuit on any ship. This has resulted in a series of numbers and letters, each number or letter representing a specific unit or wire. In general, the identification includes:

1. The main subdivision number.
2. The circuit letters.
3. The station number.
4. The particular location within the station (number).
5. The conductor number.

Take the circuit designation 2GE128—the numbers and letters represent the following:

2—Gun train order
GE—Main battery
1—Forward battery
3—Turret No. 2
8—Conductor No. 8

Had the designation been 2GE118, the meaning would be the same except that turret No. 1 receives the gun train order signal.

The above designations are for indicating quantities where the synchro receiver only positions a dial. The letter P is inserted after GE if the quantity is received automatically by the receiver regulator at the turret or gun. Thus, the same wire of the automatic signal circuit for gun train order would be labeled 2GEP118.

Now if the GE were replaced with GS, the numbers would have a similar meaning except that they would apply to the dual-purpose battery control system. Likewise, GM stands for the AA battery of heavy machine gun control circuit, and GA for torpedo control circuit.

A list of the more important circuit designations is found in appendix II in the back of this book.

Conductor Color Code

Also very useful in trouble shooting is the conductor color code used in multiple-conductor cables. The cover or sheath of each wire has either a plain color like black, white, or red, or a base color with a system of colored tracers. A number is assigned each color-code identification. Wherever possible this color-code corresponds to the conductor number in the circuit designation. For example, take the circuit for gun elevation order of the forward main battery system which connects the fine and coarse synchro transmitters to the receivers at turret No. 1; the circuit designation is 3GE11.

Synchro Leads		Circuit Designation	Color Code
Coarse	S1	3GE111	(1) Black.
Synchro	S2	3GE112	(2) White.
	S3	3GE113	(3) Red.
Fine	S1	3GE114	(4) Green.
Synchro	S2	3GE115	(5) Orange.
	S3	3GE116	(6) Blue.
Rotor	R1	3GE11	(7) White, Black tracer.
Supply	R2	3GEE11	(8) Red, Black tracer.

Notice the 3GE11 and 3GEE11 designations—these are for the 115-volt a-c synchro rotor supply. The double E is used so that all a-c rotor supply circuits can be properly phased or polarized when connecting the leads at the switchboard and units being supplied.

Before leaving this chapter, turn to appendix II in the back of the book and carefully study over the tables there. Helpful information on circuit designations, conductor color code, Navy standard cables, and wiring fittings is given. Familiarity with these tables will not only assist you in reading blue prints and wiring diagrams, but will aid you in trouble shooting and repairing fire-control circuits as well.

A Word On Safety

Unfortunately, along with the technician's expanding ability sometimes appears a growing indifference to the hazards of high voltages. It is unfortunate that there is no physical sense that warns of lethal voltages being present. So it is necessary to develop a high regard for electrical dangers. Respect high voltages, and take time to be SAFE when servicing the equipment.

Take Care of Test Equipment

Remember that electric meters are expensive, sensitive instruments. Treat them as such. After using them put the test leads and instruction pamphlet back in the case and stow the meter in its designated stowage place. When using voltmeters and ammeters, be sure the meter has a large enough capacity to do the job. Where the meter has several scale selections, ALWAYS TAKE THE INITIAL TEST AT THE HIGHEST SCALE, and then move the selector to the appropriate lower scales for fine readings.

QUIZ

The first six questions are to be answered true or false, the next six are fill-ins and the remaining ones are multiple choice.

1. A good visual inspection of most equipment will reveal signs of possible trouble.
2. Regular performances of standardized adjustments to radar equipment is an extremely effective preventive maintenance procedure.
3. Casualties to electrical circuits will consist mainly of resistor casualties.
4. Wholesale removal of tubes for tube checking is recommended.
5. Over-lubricating is often as damaging as under-lubricating.
6. Voltage and resistance data for each tube pin will be found in the OP's.
7. Cable is run into watertight boxes through ____________ tubes.
8. Pipe risers are used where cable passes through ____________ in order to prevent mechanical injury to the cable.
9. Terminal and junction boxes are rated according to the number of ____________ they can accommodate.
10. The main cause of grounds is ____________.
11. The circuit must be ____________ before ground readings are taken with the megger.
12. Circuit wiring with all wiring and appliances connected but instruments disconnected should have an insulation resistance of at least ____________ megohm(s) to ground.
13. In testing electrical circuits with a meter which has four scales, which scale should be used for the initial test?
    a. Lowest
    b. Next to the lowest
    c. Highest
    d. Next to the highest

14. Why is salt water particularly injurious to electrical equipment?
    a. Its high conductance causes grounds
    b. Its low conductance causes shorts
    c. Its low resistance causes insulation to be burned
    d. Salt precipitates out of the moisture and attacks the insulation and the wire

15. The electrical terminal and junction boxes of fire-control equipment are rated by
    a. the amount of voltage they carry
    b. the number of terminals they contain
    c. the total diameter of the wires they contain
    d. one-half of the total diameter of the wires they contain

16. In order to detect partial grounds before they become serious, daily ground tests are made at the fire-control switchboard with a
    a. patching cord
    b. megger
    c. voltmeter
    d. ammeter

17. Blown fuses, dirty slip ring contacts, and broken wires are commonly the cause of
    a. open circuits
    b. closed circuits
    c. grounds
    d. shorts

18. What do the letters GE stand for in the fire-control circuit designation 2GE128?
    a. Secondary battery
    b. Turret No. 2
    c. Main battery
    d. Gun train order

19. Which of the following fire-control circuits is designated by the letters GS?
    a. Main battery
    b. Torpedo control
    c. Gun elevation order
    d. Dual-purpose battery

20. Which of the following fire-control circuit designations applies to inputs which are received automatically by a receiver regulator?
    a. IGE
    b. 50GEZ
    c. 1GEL
    d. 3GEP

21. Which of the following fire-control designations refers to the system which transmits director train angle to the computer?
    a. 1GE
    b. 5GS
    c. 3GA
    d. 4GE

22. Which of the following designations refers to the system which automatically transmits own ship's course inputs?
    a. 2GE
    b. 3GEL
    c. 7GEP
    d. 3GM

23. In the conductor color code used for Navy IC and FC cables, what is the basic color for wire #5?
    a. Black
    b. Green
    c. Orange
    d. White

24. What is the conductor color code for wire #7 used in Navy IC and FC cables?
    a. Red base with black and white tracers
    b. White base with red tracers
    c. Red base with white tracers
    d. White base with black tracers

25. In Navy IC and FC cables, which of the following wires are designated by base colors only and have no tracer colors?
    a. Wires #1 to 6
    b. Wires #1 to 10
    c. Wires #7 to 20
    d. Wires #39 to 43

26. A Navy cable marked with the letters MHFA indicates that this cable is a
    a. double conductor, is heat resistant, and is armored
    b. multiple conductor, is heat and flame resistant, and is armored
    c. multiple conductor, is used for degaussing, and is armored
    d. four-conductor, is heat and flame resistant, and is flexible

27. A Navy cable marked with letters TCOP indicates that this cable is a
    a. multiple conductor, is used for interior communications, and is portable
    b. double conductor, is heat and flame resistant, and is flexible
    c. triple conductor, is oil resistant, and is flexible
    d. triple conductor, is oil resistant, and is portable

CHAPTER 8

SYNCHRO TRANSMITTERS AND RECEIVERS

TRANSMITTING THE INFORMATION ELECTRICALLY

It takes many inputs to solve the fire-control problem and these inputs come from all over the ship. For example, own ship's speed comes from the pitometer log. Own ship's course comes from the master gyro. And target bearing, elevation, and range come from the director.

Getting all these inputs—from all over the ship—is the job done by the SYNCHRO SYSTEMS. The synchros pick up the inputs, transmit them to the computer, and then transmit the gun orders to the gun mount. In other words, TRANSMITTING INFORMATION, accurately and instantaneously, is the job of the synchro systems.

This chapter will cover the general construction and principles of electrical operation of two synchro units—the transmitter and the receiver. Specific information on the maintenance and installation of Navy synchros should be learned by reference to OP 1140 or OP 1303.

Now, look at a diagram of a synchro system at work—figure 8–1. The transmitter receives an input mechanically—from a shaft, a set of gears, or by hand. Then, the transmitter converts the mechanical input to an electrical signal—and transmits the signal to the receiver. The receiver receives the signal and converts it to a mechanical output. This output is delivered to a mechanical load. But the mechanical load must be very light—synchro receivers become inaccurate when they're loaded appreciably. As has been stated, the whole synchro system is an information transmitting system—it simply transmits a given item of information from one part of the ship to another.

For example, say the transmitter in figure 8–1 is geared to the pitometer log. The ship's speed is the information input to the transmitter, and the transmitter transmits this signal to the synchro receiver. The receiver receives the signal and delivers it to a dial at the computer. Notice that the synchro system transmits the ship's speed from the pitometer log to the computer as an angular position with respect to a reference index.

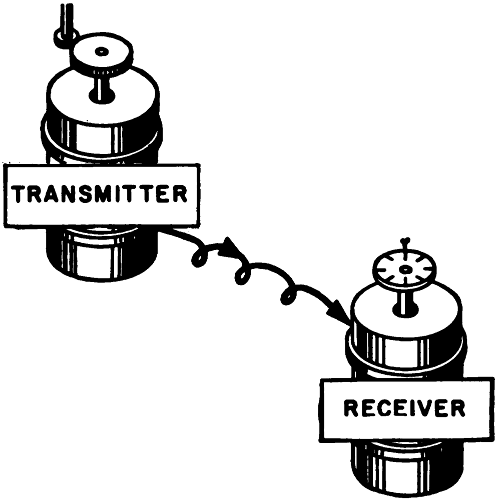


Figure 8–1.—Synchro transmitter and receiver.

Figure 8–2 is another example of how a synchro system works. Here the director measures relative target bearing *B'r*. And as the director trains, it furnishes the synchro transmitter with *B'r* as a mechanical input. Then *B'r* is transmitted to the synchro receiver at the *Dd* computer.

The computer adds *Dd* to the *B'r* from the synchro receiver. Then, *Dd* plus *B'r* becomes the input to the synchro transmitter at the computer. This transmitter at the computer transmits *Dd* plus *B'r* to the synchro receiver at the gun power drive. And this latter receiver controls a servo system that controls the power drive to train the gun

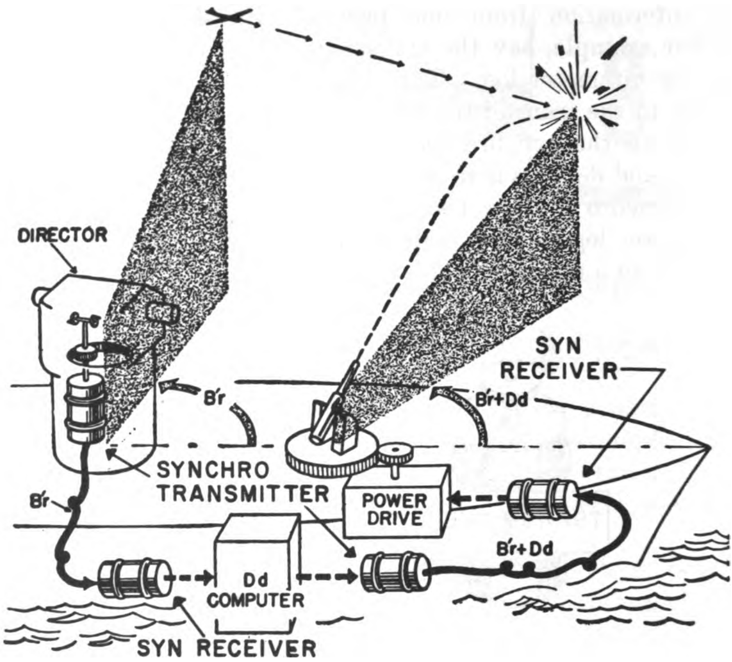


Figure 8-2.—Synchro system.

through *Dd+B'r*. Boiling it down—the director and computer position the gun through the synchro transmission system. The synchros pick up the inputs, feed them to the computer, and deliver the gun orders to the mount.

TRANSMITTER CONSTRUCTION

Figure 8–3 is a cutaway view of the synchro transmitter with all of the parts labeled. You can see that it looks very much like any ordinary transmitter or motor—with a stationary winding on the STATOR, and a winding which rotates with the ROTOR.

Stator Windings

Look at figure 8–4 and see how the windings are placed in the stator. There are three similar coil groups—spaced at

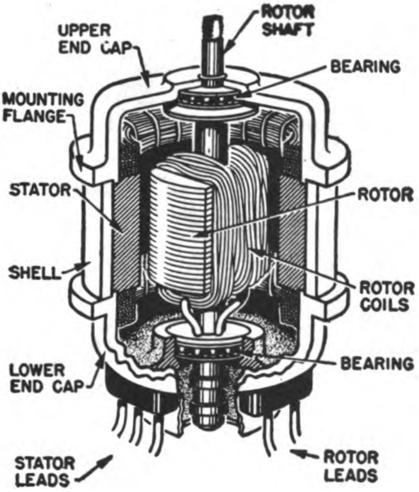


Figure 8–3.—Synchro transmitter construction.

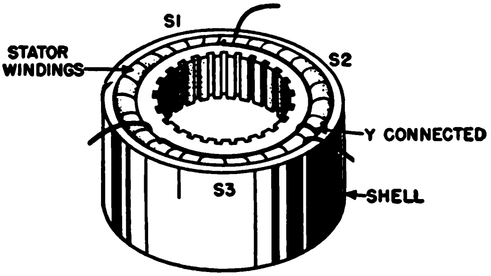


Figure 8–4.—Stator windings.

120° intervals. One lead from each coil group forms a common connection. The remaining leads are the external connections. This is a "star" connection.

Figure 8–5 shows how the stator fits into the shell and how the shell fits into the lower end cap. Notice the three stator leads, *S1*, *S2*, and *S3*. These three leads are brought out through the lower end cap.

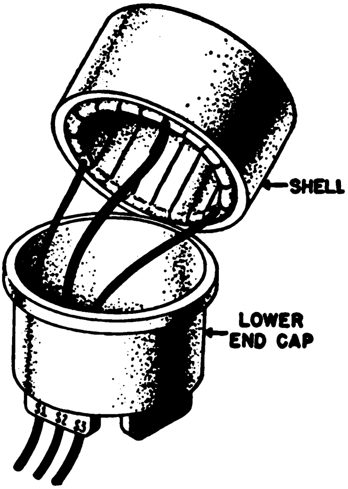


Figure 8–5.—Stator, shell, and end cap.

Rotor Windings

Figure 8–6 shows how the rotor is wound. The two rotor coils are wound on a laminated, bobbin-shaped, iron core. These two coils are connected in series to make one continuous winding.

The two leads from the rotor winding are connected to silver slip rings on the rotor shaft. And the entire rotor assembly turns on ball bearings set in the end caps. These bearings are precision machined to eliminate as much friction as possible.

The external rotor leads, *R1* and *R2*, are led IN through the lower end cap—and then right OUT again. See figure 8–7. The rotor leads are led in and out so that they can be secured to the lead clamp on the end cap. This makes a good, rugged installation—and fewer headaches for you.

Figure 8–8 shows how *R1* and *R2* are connected to the rotor windings. These leads are connected to the brushes on the lower end cap. And these brushes ride on the rotor slip rings.

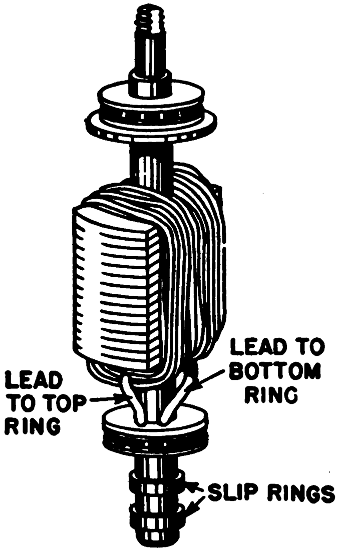


Figure 8–6.—Synchro rotor.

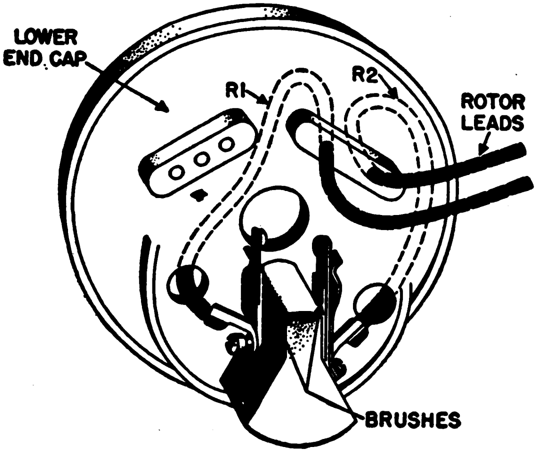


Figure 8–7.—Rotor leads.

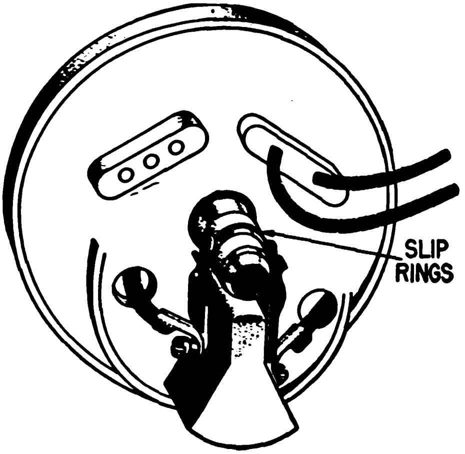


Figure 8–8.—Rotor lead connections.

Go back over figures 8–6, 8–7, and 8–8. These three figures show you the complete rotor circuit and all the details of connecting the rotor leads of typical Navy synchros. The receiver stator is exactly like the transmitter stator.

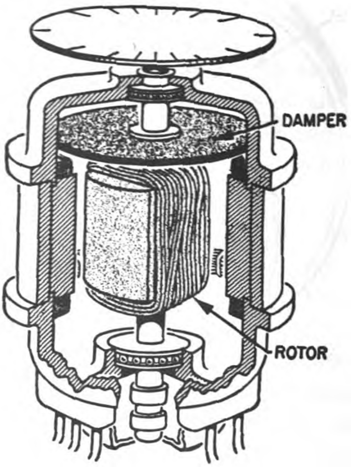


Figure 8–9.—Synchro receiver, construction.

But the receiver rotor has a DAMPER. This damper is shown in figure 8–9.

Here's the reason for the damper on the receiver rotor. The receiver is driven by an electrical signal from the transmitter. Inertia can cause the receiver to overdrive, causing oscillation as it reverses to correct the overdrive. The damper prevents oscillation by constantly decreasing the overdrive.

SYNCHRO SCHEMATICS

Look at the three synchro schematics in figure 8–10. Any one of these three diagrams can stand for either a transmitter or a receiver.

Figure 8–10A is the most common schematic. And schematic C is often used in Navy diagrams—especially electro-mechanical diagrams. But in this chapter we will use the schematic in B because it shows some of the details of the windings.

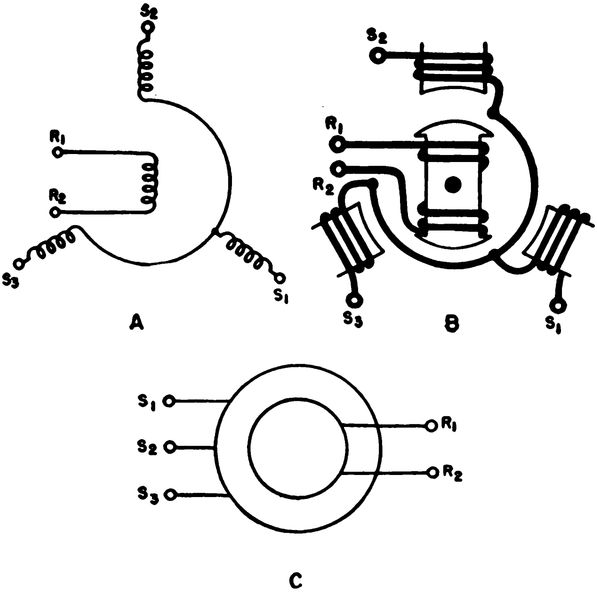


Figure 8–10.—Synchro schematics.

Transformer Action In Synchros

Synchros act like transformers. The rotor coil is the primary, and the stator coils are secondaries.

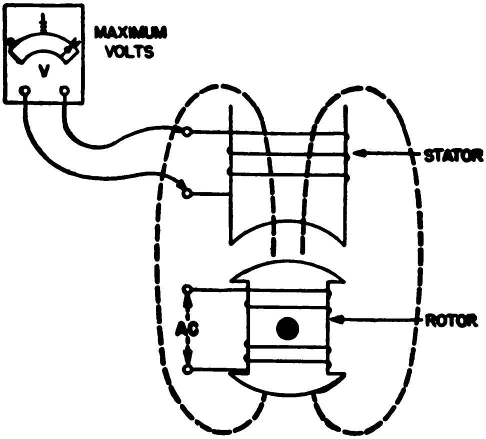


Figure 8–11.—Synchro action, 0°.

Figure 8–11 shows the transformer action between the rotor and one coil of the stator. The lower coil represents the rotor and, like all primaries, the rotor is energized by a. c. The upper coil represents one coil in the stator and, like all secondaries, the stator has a voltage induced by the primary flux.

In figure 8–11 the rotor and stator coils are lined up—they are 0° apart. All of the rotor flux cuts the stator coil and the induced voltage in the stator coil has its greatest value.

Now displace the rotor by 60°—figure 8–12. Notice the rotor flux field. With the rotor turned 60°, only one-half of the rotor flux cuts the stator coil and the induced voltage in the stator is only one-half of maximum.

Finally, displace the rotor by 90°—figure 8–13. At 90° the rotor flux is PARALLEL to the stator coil with no flux cutting the stator coil and the induced voltage is ZERO.

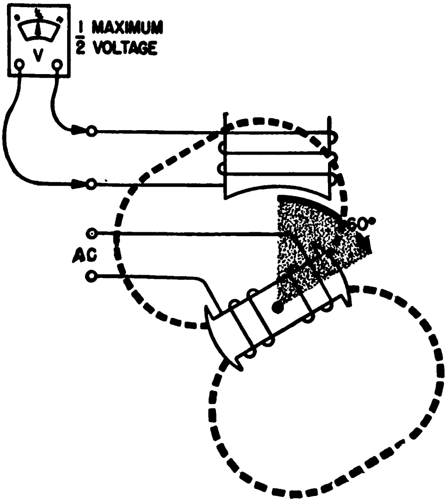


Figure 8–12.—Synchro action, 60°.

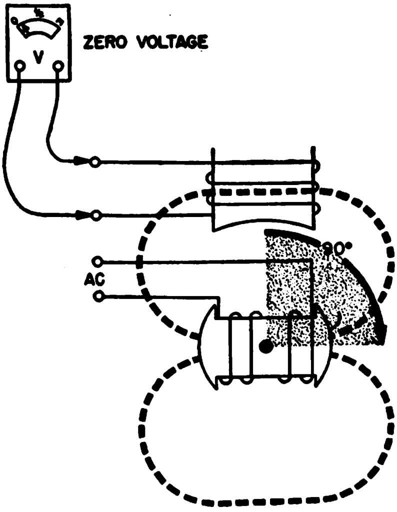


Figure 8–13.—Synchro action, 90°.

Imagine what happens as the rotor keeps on turning—past the 90° point. As the rotor turns the induced voltage again increases as more and more rotor flux cuts the stator. But, the phase of the induced voltage reverses because now the opposite rotor pole furnishes the flux.

The amount and phase of the induced voltage in the stator coil depend on the position of the rotor. The exact amount of induced voltage is proportional to the cosine of the rotor's angle of displacement. For example, in figure 8–11 the rotor is displaced by 0°. And the cosine of 0° is 1. Therefore, the induced voltage in the stator is the maximum (52 volts) times 1.

But in figure 8–12 the rotor is displaced by 60°. And the cosine of 60° is 0.5. Therefore, the stator voltage in that case is the maximum times 0.5—or, one-half maximum.

Finally, in figure 8–13, the rotor is displaced by 90°. And the cosine of 90° is zero. Therefore, the stator voltage is the maximum times zero—or, ZERO.

You can see that every different rotor position produces a different stator voltage. In other words, the stator VOLTAGE exactly defines the rotor POSITION.

Actual Synchro Voltage

All F–C synchros—both transmitters and receivers—are energized with 115-volt, 60-cycle, a. c. at their *R1–R2* leads. The turns ratio between rotor and stator is standard. This turns ratio, and the 115 volts on the rotor, produce a MAXIMUM of 52 effective volts in any one stator coil. This is standard for all F–C synchros.

Figure 8–14 shows a synchro with 115 volts a. c. applied to its rotor. The voltmeters show the voltages at the stator leads.

Notice the method of labeling polarities in figure 8–14. The dot on the positive alternation of the sine wave means that all polarities are for that instant on the positive alternation. A dot on the negative alternation would reverse all polarities in the circuit. This method of marking a-c circuits makes circuit tracing easy—get used to it now.

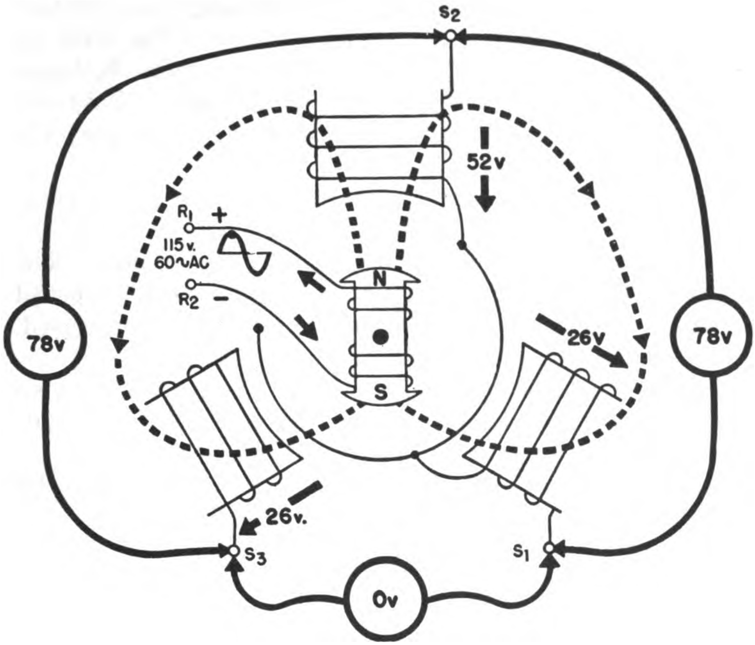


Figure 8–14.—Synchro voltages, No. 1.

Now find the voltage labels at each stator winding. The *S2* winding has the greatest voltage—52 volts. *S2* is maximum because the rotor is 0° from *S2*.

The *S1* and *S3* windings have 0.5 of this maximum voltage, or 26 volts. *S1* and *S3* have 0.5 this maximum value because the rotor is displaced 60° from *S1* and *S3*.

Compare the *S2* polarity to the polarity of *S1* and *S3*. They're opposite because an *N*-pole flux cuts *S2* and an *S*-pole flux cuts *S1* and *S3*. The opposite polarities tell you that the *S2* phase is opposite to the *S1* and *S3* phase.

Now go back to figure 8–14 and notice the voltmeter readings. The meters between *S1* and *S2*, and between *S2* and *S3*, read 78 volts. The readings are 78 volts because the 52 volts of *S2* ADD to the 26 volts of both *S1* and *S3*. But the meter between *S1* and *S3* reads 0 volts. The *S1*–*S3* reading is zero because the *S1* and *S3* voltages CANCEL each other—they're equal and opposing.

Now turn the synchro rotor 60° in the clockwise direction as is shown in figure 8–15. A 60° turn lines the rotor up with the *S3* winding. Notice the changed stator voltages. Now *S3* is 52 volts, while *S1* and *S2* are 26 volts. You know why—*S3* cuts all the rotor flux, while *S1* and *S2* cut only one-half the rotor flux.

Be sure to notice that *S1* REVERSED PHASE as the rotor turned 60°. In figure 8–14, *S1* was cut by the *S* pole of the rotor. But in figure 8–15, *S1* is cut by the *N* pole. The reversed flux reverses the *S1* phase. Here's what happened as the rotor turned—the *S1* voltage fell to zero, reversed, and then built up to 26 volts of the opposite phase.

Finally, turn the rotor another 60°. Now it's 120° from the original position and you get figure 8–16. The 120° position lines-up the rotor with the *S1* winding.

All the voltages and polarities are labeled in figure 8–16. You figure them out.

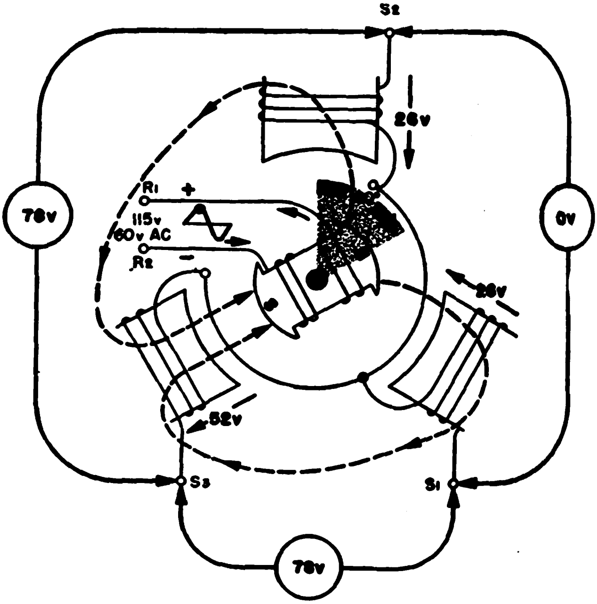


Figure 8–15.—Synchro voltages, No. 2.

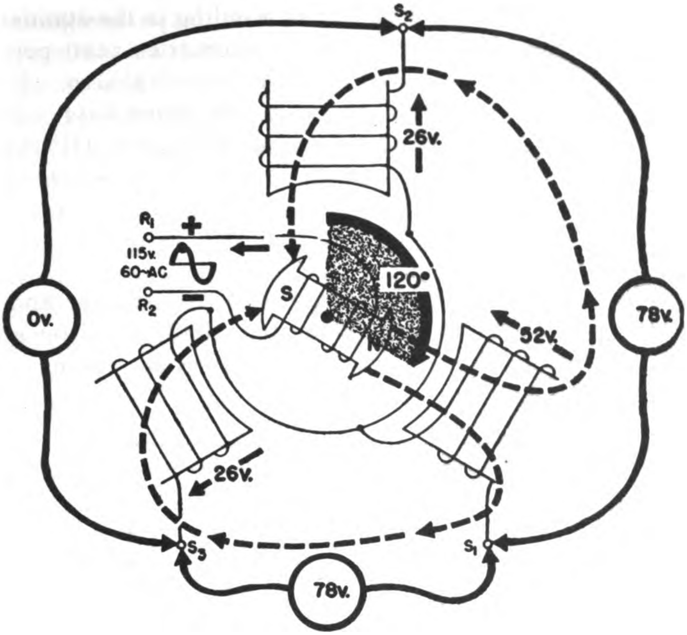


Figure 8–16.—Synchro voltages, No. 3.

Review the voltages induced in each stator coil as the rotor turns. Each stator coil takes its own turn in building up to a maximum voltage, falling to zero voltages, reversing phase, and building up to a maximum again. Be sure to see the relationship between the rotor position and the induced voltages. Every rotor position induces its own set of voltages in the stator.

Remember—you've been looking at both TRANSMITTERS AND RECEIVERS. The stator voltages are just the same in both units because they're constructed the same and both have 115-volt, 60-cycle a. c. on their rotors.

Electrical Zero

Go back to figures 8–14, 8–15, and 8–16 and look at the method of measuring the rotor position. In each case the rotor angle is measured from the *RI* pole to the center of the

S2 winding. The center of the *S2* winding is the standard reference point and it's called the ELECTRICAL ZERO point. All rotor angles are measured from this electrical zero. You can see the synchro set at electrical zero in figure 8–14. But for methods of adjusting the electrical zero, go to OP 1140, OP 1303, or the Navy Training Course, *Basic Electricity*, NavPers 10086.

Synchro Systems

Figure 8–17 shows how to connect a transmitter and a receiver together. Properly connected, the transmitter and receiver make a complete synchro transmission system.

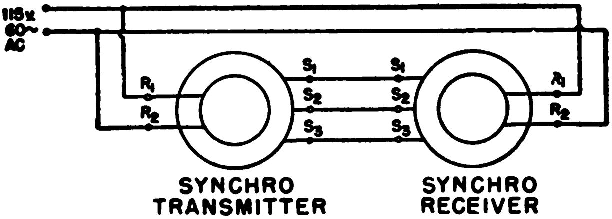


Figure 8–17.—Transmitter and receiver, connected.

First, notice the rotor connections. Both *R1* leads are connected to the other side of the supply line. This means that both rotors get exactly the same supply—the same voltage, the same phase, and the same frequency.

Next, notice the stator connections. The stators are connected lead for lead. That is, *S1* is connected to *S1*, *S2* to *S2*, and *S3* to *S3*.

With the two stators connected, lead for lead, they act like bucking transformers. The motor's *S1* voltage opposes the generator's *S1* voltage. Likewise, the two *S2* voltages oppose each other, and the two *S3* voltages oppose each other.

If both rotors are displaced by the same amount, they are in CORRESPONDENCE. And at correspondence the induced voltages in the two *S1* coils are equal—the induced voltages in the two *S2* coils are equal—and the induced voltages in the two *S3* coils are equal. Since the stator voltages are bucking and equal, they cancel each other. The result is—no resultant voltages on the stator windings and NO CURRENT in the stators.

But remember that the transmitter rotor is turned and held in position mechanically, whereas the receiver rotor is free to turn. Now, if the two rotors are NOT displaced by the same amount, the voltages across *S1–S1*, *S2–S2*, and *S3–S3* are NOT equal. And the unequal voltages set up currents in the stator windings. These currents create stator flux fields that exert torque on the rotors. Result—the transmitter rotor remains stationary because it is held mechanically, but the receiver rotor is turned by the torque.

The turning of the receiver rotor is the important part of synchro action—see how it works in the next section.

Synchro Action

Figure 8–18 shows the transmitter and receiver in correspondence. Both rotors are displaced by 0°. In other words, both rotors are at electrical zero.

Compare the stator voltages and polarities in figure 8–18. The stator voltages cancel each other because *S1* equals and bucks *S1*, *S2* equals and bucks *S2*, and *S3* equals and bucks *S3*. Result—current is zero, no torque is produced, and the rotors remain stationary.

Figure 8–19 shows the beginning of synchro action. First, the generator rotor is displaced mechanically. This displacement is called signal. The signal can be any amount of displacement—from a fraction of a degree up to 360°. The signal in figure 8–19 is 60°. Just as soon as the transmitter rotor is turned, the voltages in the generator stator change. The voltage of the *S1* coil decreases, the *S2* coil voltage reverses phase, and the *S3* coil voltage increases. Immediately, current flows between the two stators—always in the direction determined by higher voltage.

Trace out the stator currents for the 60° signal. Notice what the stator currents do in the receiver. The stator currents set up an *N* pole at *S2*, an *S* pole at *S1*, and an *N* pole at *S3*. These stator poles create the torque on the

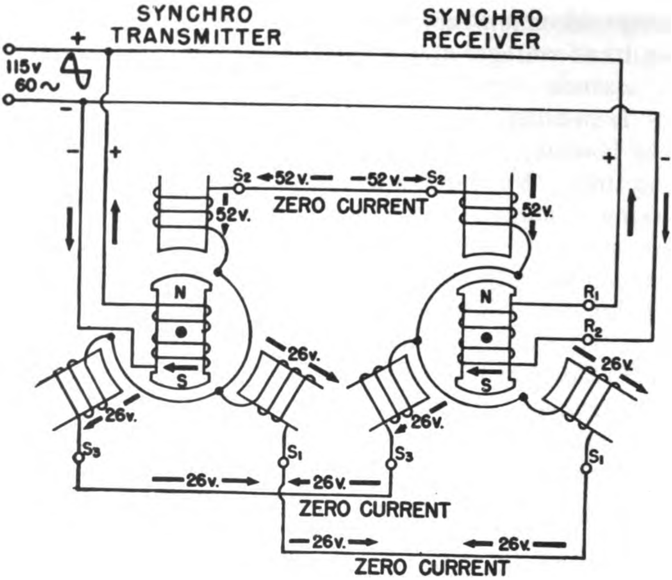


Figure 8–18.—Synchro action, No. 1.

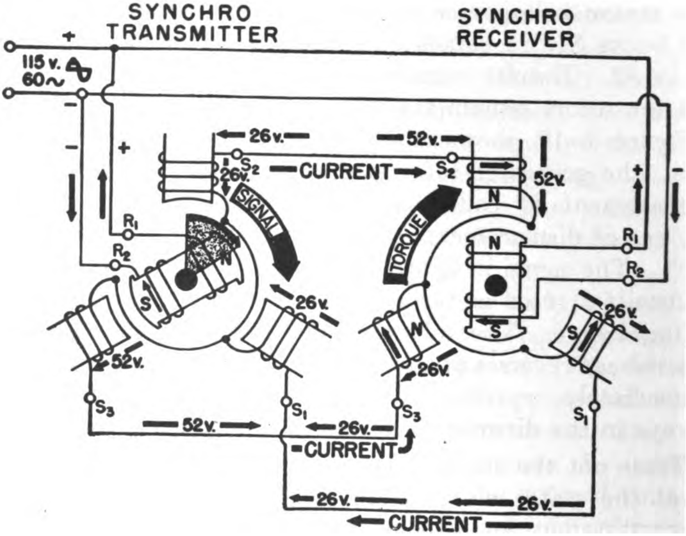


Figure 8–19.—Synchro action, No. 2.

receiver rotor. Result—the receiver rotor turns in the direction of the torque.

Figure 8–20 shows how far the receiver rotor turns. The torque turns the receiver rotor until the stator voltages in the transmitter and receiver are AGAIN EQUAL—until current stops because the voltages cancel each other. You know that the stator voltages are equal when the rotors are in correspondence. Thus, the receiver rotor turns 60° which is the same amount as the signal at the transmitter.

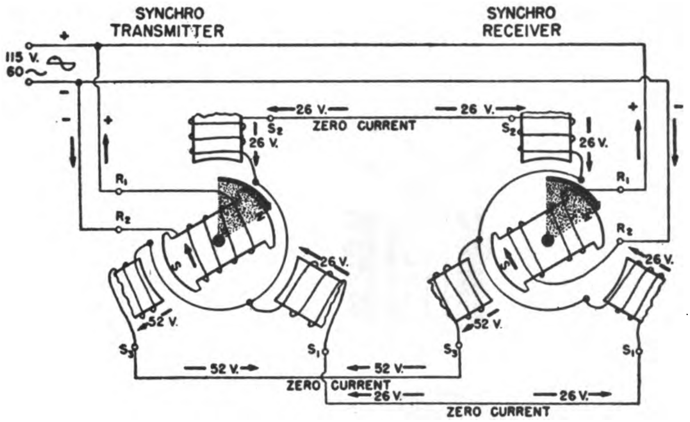


Figure 8–20.—Synchro action, No. 3.

Take another example of synchro action. Suppose the signal in figure 8–19 is 43° instead of 60°. The 43° signal unbalances the stator voltages and torque turns the receiver rotor, but this time it turns only 43° because at 43° displacement both rotors are in the same position and the stator voltages cancel each other. Then current stops, and the torque is zero.

Here's a review of synchro action. Any signal at the transmitter unbalances the stator voltages and these unbalanced voltages produce current in the stator coils. This current sets up stator flux fields which, in turn, exert a torque on the receiver rotor. The torque turns the receiver rotor until its position corresponds to that of the transmitter rotor. Thus the receiver follows every move of the transmitter rotor. Or, in other words, the receiver delivers the signal that was put in at the transmitter.

Synchro Loads

As a synchro receiver approaches correspondence with a synchro transmitter, the stator voltages approach cancellation. This decreases stator current and the decreased current produces less and less torque on the motor rotor. Finally, at correspondence, the torque on the motor rotor becomes zero. This decreasing torque means that the syn-

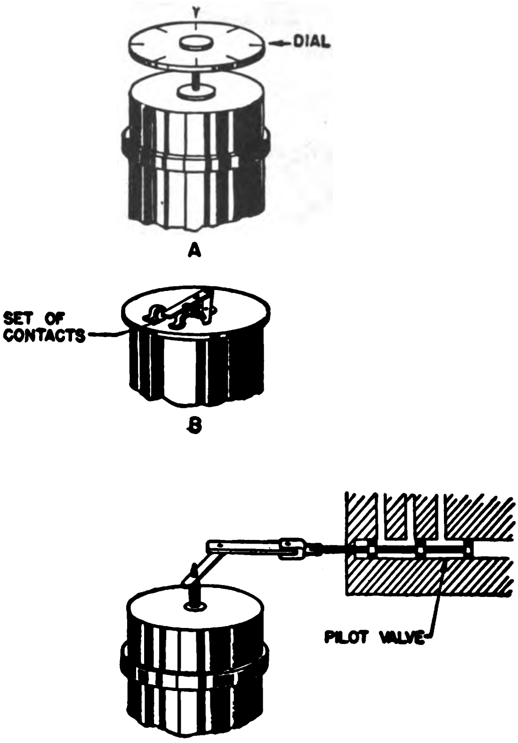


Figure 8-21.—Synchro loads.

chro receiver loses accuracy, and therefore cannot position a heavy load at or near correspondence.

Because of their weak torque near correspondence, synchros are always used to position very light loads. Figure 8–21 shows three examples of the light loads that a synchro receiver can position accurately.

Figure 8–21A shows a synchro positioning a dial. Drawing *B* shows a synchro positioning a set of contacts. And *C* shows a synchro positioning a pilot valve in a hydraulic system. You will notice that each load requires but a SMALL TORQUE.

Synchro Sizes

Many installations connect one transmitter to a number of receivers. Whenever this is the case, the transmitter stator must carry all the currents which means that a bigger transmitter is required.

OP 1303 gives information on synchro sizes, but here are a few examples that will give you the general idea. A size-1 transmitter can drive a maximum of only two size-1 receivers and a size-5 transmitter can drive only two size-5 receivers. A size-6 transmitter, however, can drive nine size-5 receivers and a size-7 transmitter can drive eighteen size-5 receivers.

Standard Connection

Regardless of the size and number of synchros used, all installations use a standard type of connection. Look at this standard connection in figure 8–22. Notice that all the rotor leads are connected to the same supply line—all *R1* leads to one side and all *R2* leads to the other side. Now check the stator leads and see that all the receiver stator leads are paralleled across the transmitter stator leads.

Additional equipment frequently goes into synchro installations (such as rotary switches, fuses, and overload indicators). For the details regarding this additional synchro equipment you should go to OP 1303.

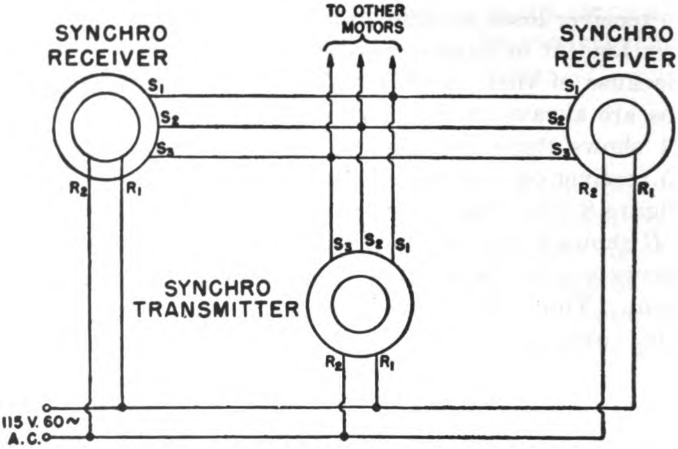


Figure 8–22.—Synchro connection.

Bearing-Mounted Synchro Receiver

Electrically, the bearing-mounted synchro receiver is exactly like the ordinary synchro receiver and transmitter, but mechanically the bearing-mounted synchro is different. It's designed to receive a regular electrical signal in the stator which is transmitted to the rotor in the usual manner; it is also built to receive a mechanical signal at the stator.

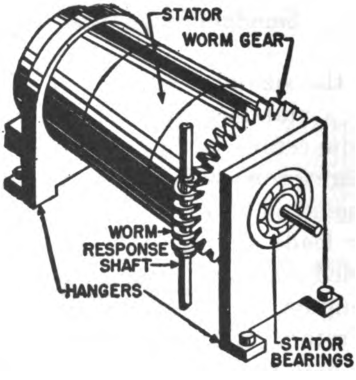


Figure 8–23.—Mounting of a bearing-mounted synchro.

Look at the mounting of a bearing-mounted synchro—figure 8–23. The ball bearings mount the synchro stator so that it can be turned mechanically. This is accomplished with the response shaft and gearing when there is a mechanical signal to be delivered to the stator.

With the stator bearing-mounted, the stator leads must be brought out to slip rings and brushes so that the stator can be turned mechanically and still maintain electrical contact. You'll see the slip ring end of the stator in *A* of figure 10–24.

Figure 8–24B shows how the stator leads are connected to the slip rings. And *C* of figure 8–24 shows the brushes and brush leads.

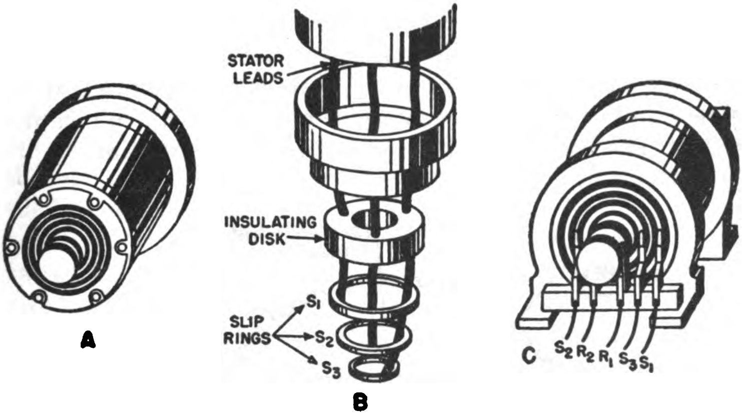


Figure 8–24.—Electrical connections of a bearing-mounted synchro.

Figures 8–23 and 8–24 show how the bearing-mounted synchro receives two signals. The electrical signal is received via the *S1–S2–S3* leads (fig. 8–24)—it rotates the rotor within the stator. And the mechanical signal is received via the response shaft and gears (fig. 8–23)—it rotates both the stator and the rotor. The rotor turns with the stator when the stator is being turned mechanically because the stator flux holds the rotor in position with respect to the stator.

Bearing-Mounted Action

Bearing-mounted synchros are usually used to operate a set of electrical contacts. Then these contacts control a SERVO MOTOR. The servo drives whenever the synchro closes the contacts. Thus, the servo actually operates until the synchro signal is satisfied.

You're probably wondering why the synchro receiver doesn't do the work required by the signal DIRECTLY. The reason is simply—the loads are fairly heavy when, for example, a twin system is used and the synchro doesn't have enough torque to drive them. So the synchro controls a servo. And since the servo does have the torque to drive the loads, the servo does the work for the synchro.

Look at figure 8–25, which shows one end of a synchro receiver, to see how the bearing-mounted synchro controls the servo contacts. The response shaft of the synchro is driven by the servo motor and it rotates the synchro stator. Now, find the HEART CAM and CONTACT ARM on figure 8–25. The contact arm is secured to the heart cam.

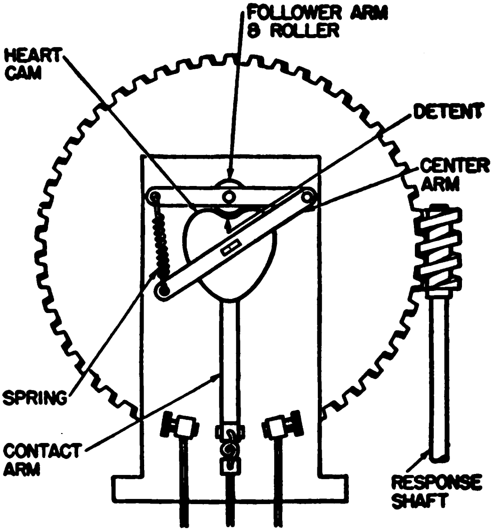


Figure 8–25.—Bearing-mounted contacts.

But both the arm and cam are ball bearing-mounted on the synchro rotor shaft—neither the arm, the contact nor the cam turns DIRECTLY with the rotor shaft. But the CENTER ARM is secured to the rotor shaft. This center arm drives the FOLLOWER ARM and ROLLER. The SPRING keeps the roller in the DETENT of the heart cam.

Now, imagine an electrical signal turning the rotor. As the rotor turns, the center arm, follower arm, and roller drive the heart cam. And as the heart cam rotates, it closes the contacts at the contact arm. This closes the circuit to the servo, and the servo starts driving.

As the servo drives its load, it also drives the response shaft, and the response shaft turns both the synchro stator and rotor. As the stator and rotor turn in response, the heart cam drive tends to open the contacts. But these contacts are not opened until the response equals the original signal—until the rotor is turned as much by RESPONSE as it was turned by the electrical signal. This means the contacts open and stop the servo as soon as the servo has driven out the signal. Result—the servo drives out the signal given by the bearing-mounted synchro.

Briefly, the ELECTRICAL SIGNAL to the rotor STARTS THE SERVO. And the mechanical RESPONSE to the stator STOPS THE SERVO.

Figure 8–26 reviews this signal-response action. Figure 8–26A shows the signal turning the synchro rotor and closing the servo contacts. This starts the servo driving.

Figure 8–26B shows the response driving both stator and rotor of the synchro receiver. When the response equals the signal, the contacts are CENTRALIZED and this STOPS THE SERVO.

Net result in figure 8–26—the servo shaft has driven out the original electrical signal. Not only has the servo driven out the signal, but it has driven with ENOUGH TORQUE to position a fairly heavy load.

You're probably wondering why the contact arm here is driven by the heart cam assembly. Here's the reason: A large electrical signal turns the synchro rotor with considerable torque. The torque closes the contacts at the contact

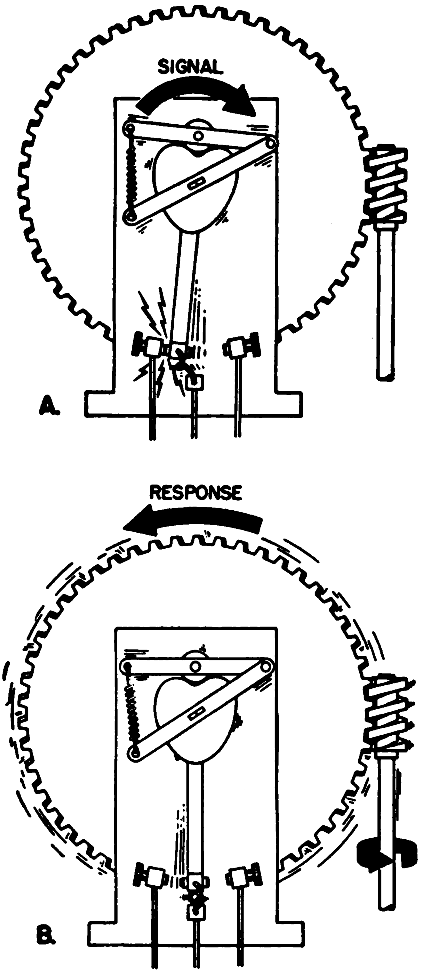


Figure 8-26.—Signal-response action.

arm. Then as soon as the contacts are closed, the spring stretches and the roller gently rolls out of the detent. This frees the rotor so that it can follow the signal—without exerting any more force on the contacts.

Without the heart cam drive, the rotor would continue to drive against the closed contacts. And this might damage the contacts or throw the rotor itself out of line. Thus, the heart cam drive prevents damage for large electrical signals.

There's another reason for the heart cam drive. Without the heart cam drive, a power failure at the servo would interrupt the response drive and hold the rotor OUT of correspondence. And large currents would probably damage the stator windings. But with the heart cam drive, the roller rolls out of the detent and allows the rotor to turn to correspondence.

Synchro Follow-Up

When a bearing-mounted synchro is driven in response, it's called a SYNCHRO FOLLOW-UP system. Follow-up because the response follows the signal and stops the servo as soon as the servo has driven out the signal.

Figure 8–27 shows a simple, but complete, synchro follow-up system. You already know about each unit—the transmitter, the bearing-mounted receiver, and the servo motor. Now let us see how they all work together in the parallax mechanism for the single 5″/38 GE power drive.

The electrical signal (Ph) from the Mk 1A computer is fed to the bearing-mounted parallax receiver via *S1*, *S2*, and *S3*. This signal turns the parallax receiver rotor—in the direction corresponding to the signal. The turning parallax receiver rotor drives the heart cam to close the proper set of servo contacts which energize the servo motor. The servo motor drives the parallax mechanism until the proper amount of parallax has been introduced into the power drive. Then response repositions the synchro stator and rotor which in turn centers the contact arm. This movement shuts off the current to the servo motor until the synchro rotor moves to a new position as the result of a new signal.

In short, as the servo drives, it does two things. First, the servo drives out the signal at its output shaft—WITH TORQUE. And second, the servo drives the synchro stator and rotor in response. When the response equals the signal, the contacts open and the servo stops.

There are several other types of follow-ups. But they all operate on the principle of the circuit in figure 8–27. If you want to see more of the details see OP 1140.

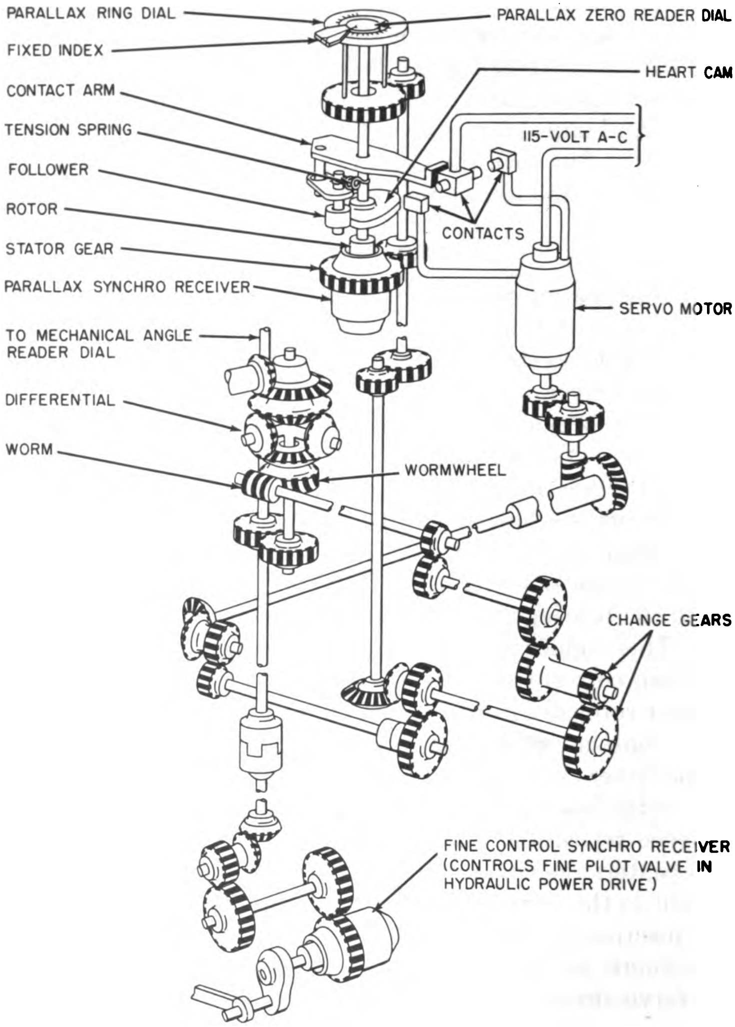

PARALLAX RING DIAL
PARALLAX ZERO READER DIAL
FIXED INDEX
HEART CAM
CONTACT ARM
TENSION SPRING
115-VOLT A-C
FOLLOWER
ROTOR
CONTACTS
STATOR GEAR
PARALLAX SYNCHRO RECEIVER
SERVO MOTOR
TO MECHANICAL ANGLE READER DIAL
DIFFERENTIAL
WORM
WORMWHEEL
CHANGE GEARS
FINE CONTROL SYNCHRO RECEIVER (CONTROLS FINE PILOT VALVE IN HYDRAULIC POWER DRIVE)

Figure 8–27.—Parallax synchro follow-up.

QUIZ

1. What information is supplied from a pitometer log in a fire control system?
   a. Own ship's speed
   b. Own ship's course
   c. Target bearing
   d. Target range
2. What is the main purpose of a synchro system?
   a. To generate a-c power
   b. To generate d-c power
   c. To transmit information
   d. To eliminate voltage transients
3. The generator unit of a synchro system is called a
   a. transmitter
   b. receiver
   c. follower
   d. motor
4. The energy transformation accomplished in a synchro receiver is from
   a. electrical energy to mechanical energy
   b. mechanical energy to electrical energy
   c. heat energy to mechanical energy
   d. chemical energy to electrical energy
5. In a fire-control system, information concerning own ship's course is fed to the computer from the
   a. director
   b. pitometer log
   c. master gyro
   d. radar receiver
6. Which of the following precautions is taken with regard to the load of a synchro receiver?
   a. A buffer is inserted between the follower and the load.
   b. The follower output voltage is carefully filtered before it is fed to the load.
   c. The mechanical load is kept light.
   d. The transformation ratio is made relatively large.
7. In a typical synchro system, information is transmitted from the
   a. gun to the computer
   b. gun to the director
   c. computer to the director
   d. computer to the gun

8. The energy that directly rotates the gun mount in a fire-control system is obtained from a
    a. synchro motor
    b. synchro generator
    c. power drive unit
    d. computer
9. The design of the stator windings of a synchro transmitter resembles most closely that of a
    a. three-phase star-connected generator
    b. two-phase, three-wire alternator
    c. single-phase, two-pole alternator
    d. three-phase delta-connected generator
10. Which of the following parts of a synchro transmitter rotates during normal operation?
    a. Rotor
    b. Shell
    c. Upper end cap
    d. Stator
11. What is the total number of electrical connections made to a synchro transmitter or receiver?
    a. Two
    b. Three
    c. Five
    d. Eight
12. Electrical connection is made from the external circuit to the rotor of a synchro transmitter through a
    a. brush-commutator system
    b. damper assembly
    c. step-down transformer
    d. brush slip-ring system
13. The construction of a synchro receiver differs from that of a synchro transmitter in that the receiver uses
    a. a different type of stator connection
    b. a different type of rotor connection
    c. fewer windings
    d. an oscillation damper
14. What is the purpose of the damper used on a synchro receiver rotor?
    a. To eliminate even harmonics
    b. To eliminate odd harmonics
    c. To prevent oscillation
    d. To increase sensitivity
15. The operating principle of a synchro is similar to that of
    a. a capacitor
    b. an inductance
    c. a transformer
    d. a vacuum tube

16. What type of voltage is used to energize a synchro rotor?
    a. Single-phase a-c
    b. Pulsating d-c
    c. Steady d-c
    d. Three-phase a-c

17. What is the degree of rotor displacement of a stator coil that is receiving a maximum of induced voltage?
    a. 0°
    b. 45°
    c. 60°
    d. 90°

18. The amount of voltage induced in any stator winding of a synchro is directly proportional to the
    a. sine of the rotor displacement angle
    b. cosine of the rotor displacement angle
    c. tangent of the rotor displacement angle
    d. cotangent of the rotor displacement angle

19. What is the standard voltage used for Navy F-C synchros?
    a. 115 v. d-c
    b. 200 v. d-c
    c. 115 v. a-c
    d. 220 v. a-c

20. What is the maximum voltage that can be induced in any one stator coil of a standard F-C synchro?
    a. 52 v.
    b. 60 v.
    c. 115 v.
    d. 220 v.

21. When two synchro stators are connected lead-for-lead, their action is most similar to that of
    a. auto transformers
    b. bucking transformers
    c. tuned transformers
    d. isolation transformers

22. If maximum voltage is induced in one stator winding of an F-C synchro, what is the voltage across each of the other stator windings?
    a. 52 v.
    b. 60 v.
    c. 26 v.
    d. 115 v.

23. If the voltage across one stator winding of a synchro is at a maximum, what is the algebraic sum of the voltages across the other two stator windings?
   - a. 0 v.
   - b. 26 v.
   - c. 52 v.
   - d. 115 v.

24. The electrical zero point of a synchro is the center of the
   - a. rotor winding
   - b. S_1 winding
   - c. S_2 winding
   - d. S_3 winding

25. All the rotors of a complete synchro transmission system are supplied with a voltage of the same
   - a. magnitude only
   - b. phase and frequency only
   - c. frequency only
   - d. magnitude, phase, and frequency

26. When the rotors of a synchro transmission system are in correspondence, the voltage induced in S_1 of the transmitter is canceled by the voltage produced in
   - a. S_2 of the generator
   - b. S_2 and S_3 of the generator
   - c. R_1 of the generator
   - d. S_1 of the receiver

27. The torque produced at the rotor of a synchro receiver is a result of the interaction of the magnetic fields of the
   - a. transmitter rotor and the transmitter stator
   - b. transmitter rotor and the receiver rotor
   - c. receiver rotor and the receiver stator
   - d. transmitter rotor and the receiver stator

28. The mechanical displacement of a synchro transmitter rotor is called the
   - a. torque
   - b. load
   - c. signal
   - d. response

29. What is the maximum possible displacement of a synchro transmitter rotor?
   - a. 45°
   - b. 90°
   - c. 180°
   - d. 360°

30. When a synchro system is working, torque is produced, and the rotor of a synchro receiver turns until the
    a. voltage across the receiver rotor is zero
    b. voltage across the transmitter stator is zero
    c. current in the receiving stator is zero
    d. current in the receiver rotor is zero

31. Why is a synchro receiver NOT used with a heavy load?
    a. There is never any torque produced at the receiver shaft
    b. The torque of the receiver shaft decreases to zero at correspondence
    c. It is impossible to use an input voltage sufficient to drive a larger receiver
    d. No power is consumed in a synchro transmission system

CHAPTER 9

SAFETY PRECAUTIONS

A BAD ACCIDENT

Fred was a husky Fire Control Technician with a bright future. He had passed the qualifications for advancement to Fire Control Technician 1, and was all set to get married as soon as his new rate came through. Every man in the fire-control gang liked Fred, from the Chief on down. He took orders quickly and carried them out efficiently. But he had one serious fault; he was always a bit rough on himself. He invariably had a finger patched up or a sprained wrist, and was a steady customer in the sick bay.

One afternoon, while working on a new A. A. director, Fred made a slip that sent him out of the Navy and into an invalid's chair for life. In violation of safety regulations he was working on an energized high-voltage circuit in a compartment big enough for only one person. Turning suddenly to reach for a tool, he threw himself off balance momentarily, and his head struck a high-voltage electrode.

When he regained consciousness several hours later, Fred was terribly sick. In a matter of seconds his healthy young frame had been damaged beyond repair. The doctors were amazed that he had recovered at all. Today, Fred wears a silver plate in his head. He is limping through civilian life trying to keep out of the hospital long enough to hold down a job, and his dreams of wearing that coveted chief's crow on his arm are gone.

Bureau of Ordnance Manual

You can avoid mistakes like Fred's by observing the safety precautions the Navy has prepared for you. Through long experience the Navy has devised a set of safety regulations that is hard to beat. Consequently, the number of accidents occuring in the Navy is comparatively small. Most of the safety precautions applicable to Fire Control Technicians are published in the *Bureau of Ordnance Manual.* It is up to all petty officers of the gunnery division aboard ship to familiarize themselves thoroughly with these precautions. Many of these safety regulations have resulted from actual experiences, so give them every possible consideration.

Causes of Accidents

The precautions set forth in the *Bureau of Ordnance Manual* apply generally to the operation procedures with ordnance equipment and to the handling of explosives. However, the Navy does not expect blind adherence to them during extraordinary occasions; it is equally important that each individual use his own ability and initiative to prevent accidents during unforeseen conditions. For this reason it will be well for you to review a few of the basic causes of accidents.

There are four closely related causes of accidents: CARELESSNESS, INEXPERIENCE, OVERCONFIDENCE, and FATIGUE.

CARELESSNESS is something most human beings have to overcome. You have to cultivate good working habits—you must learn to coordinate your mental and physical actions to a point where you can concentrate on the important parts of the job at hand without having to worry about the minor mechanical functions pertaining to it.

INEXPERIENCE can be the cause of accidents regardless of how careful the individual intends to be. The best solution to this problem is NEVER GUESS—you must learn to ask questions about things you are unfamiliar with or are not completely sure about. Beginners have a tendency to be overeager and desire to put their hands to work. Eagerness is a good trait in any person, but you must realize that men with more experience usually know best. Work into a job gradually and be particular about thoroughness; always be conscious of correct procedures in doing things. Train your mind and hands to function correctly so as to protect yourself and others from physical injury. For example, when you work with a screwdriver, be sure that your left hand (or right hand, if you are left handed) is clear of the screwdriver bit, otherwise a slip of the screwdriver may drive the bit completely through your hand or may gouge deep into your arm. If you practice correct methods from the start, they'll become automatic before you realize it.

OVERCONFIDENCE can come to both young and old, experienced and inexperienced; however, it is usually more closely associated with inexperience. Often, however, men grow overconfident when they become thoroughly familiar with a particular job, and have a tendency toward carelessness. To put it briefly, always be confident that you know a job, but beware of overconfidence because it may invite mistakes which can cause accidents.

FATIGUE has always been the cause of a large percentage of accidents. You might be highly efficient when you have energy to burn, but it's another story when you get tired; your physical actions slow up and become inaccurate. Always prepare yourself for the task ahead by learning how much endurance it requires, and then get the necessary sleep, recreation, food, and exercise to keep on your toes. Remember, to be alert and to feel your best is extremely important on the job, and you can only enjoy this feeling by keeping yourself in good physical condition.

General Safety Precautions

Although many specific safety precautions are laid down for you in the *Bureau of Ordnance Manual,* and warning and caution signs are posted throughout every ship, there are a few general precautions which you should remember. Let's start by discussing the handling of hand tools and power tools.

Handling Tools

Many accidents occur because of the improper handling of tools. In general, these accidents occur in the form of physical injury to the person operating the tools. For instructions on the correct methods of handling tools you can refer to *Basic Hand Tool Skills*, NavPers 10085. The following list gives the more important general precautions to follow:

1. Whenever chipping, buffing, or grinding with hand tools and powered tools, always wear goggles as a protection to the eyes. Little chips from a spinning grind wheel, or a bristle from a revolving wire brush can easily put out an eye. Many of these machines are provided with a guard; be sure to use it.

2. Always wear goggles or hood as specified when arc welding or working with another person who is welding; otherwise severe burns to your eyes and face may occur from the ultra violet rays generated by the arc.

3. Always ground the provided ground lead located at the plug of portable tools such as electric drills to protect yourself from shock in case a ground occurs within the tool.

4. When working with sharp hand tools, always work so that the tool is moved or thrust away from the body.

5. Never wear loose clothing or a neckerchief when working with rotating tools or machinery. Such clothing may become caught in the spinning parts and drag you bodily into the machine causing severe physical injury.

6. Never use metal hand tools on energized electrical equipment or circuits because you may get shocked, or the tool may cause a short circuit causing molten copper to be blown into your face and eyes.

7. Never use hand tools around running machinery, nor perform adjustments to running machinery unless absolutely necessary.

8. Never lay hand tools on top of running machinery where vibration may cause the tool to fall into exposed working parts.

9. In the event your division officer deems it necessary to work on high-voltage (exceeding 150 volts to ground) electric equipment while in an energized state, wear rubber gloves and use tools with insulated handles, and stand on an insulated mat. Always work with one hand in order to prevent

the possibility of a circuit through your body from arm to arm.

10. When working with tools, always work in a physically comfortable position, and keep the weight of your body well centered.

Working With Machinery

In addition to the general precautions on the use of tools, there are a few other precautions which should be observed when you work with machinery. The more important ones are listed below:

1. Never remove a guard or cover from a running machine.
2. Never operate mechanical or powered equipment unless you are thoroughly familiar with its controls. When in doubt, consult the appropriate instruction pamphlet or ask someone who knows.
3. Always make sure that everyone is clear before starting or operating mechanical equipment.
4. Never try to clear jammed machinery without first cutting off the source of power.
5. When hoisting heavy machinery by a chain fall, always keep everyone clear, and guide the hoist with lines attached to the equipment.
6. Never plug in portable electric machinery without insuring that the source is the kind of electricity (a. c. or d. c.) called for on the name plate of the machine.

Electrical Work

The following list is in addition to those precautions on hand tools and machinery, and is applicable to all electrical work. This list will help you prevent electric shock or burns during daily work:

1. Whenever possible, operate electric switches and controls with one hand.
2. Do not block high-voltage protective cutouts on doors or covers to keep the circuit energized with the cover off. It is intended that work be performed on such electrical equipment while the circuit is deenergized.

3. Always be sure that all condensers are fully discharged before commencing work on a deenergized high-voltage circuit.

4. Tag the switch OPEN (open the switch and place a tag on it stating "do not energize") at the switchboard supplying power to the circuit on which you wish to work, and, when possible, remove the fuses protecting the circuit and place them in your tool box for safe keeping until the job is complete.

5. Always remove fuses with fuse pliers, and never remove fuses until after opening the switch connecting the circuit to the source of supply. Never replace a fuse with one LARGER than the circuit is designed to take.

6. Utmost precaution should be observed when inspecting behind an open-back switchboard in an energized state.

7. Never use an incandescent test lamp unless its voltage rating is greater than the highest voltage which may be tested.

8. Always test a supposedly deenergized circuit with a voltage tester before commencing work on the circuit.

9. Never work on an electric circuit or network without first thoroughly acquainting yourself with its arrangement and with its points of power feed.

Operating Fire-Control Equipment

Let us repeat—you should acquaint yourself thoroughly with the safety regulations provided in the *Bureau of Ordnance Manual*, and with those regulations posted aboard ship, before operating fire-control equipment. You will be taught how to apply many of these precautions while you are learning to operate fire-control instruments. The following list of general precautions will assist you:

1. Always inspect all training and elevating areas to make certain that all persons are clear, and that the areas are free of obstructions before operating directors, turrets, or guns.

2. Always use warning bells where provided before training or elevating gun mounts or turrets during routine work and practices (except during GQ).

3. Before leaving directors, turrets, or guns, always train and elevate them to their securing positions, place all controls in the inoperative positions, and deenergize all power supplied to them.

4. Whenever possible, have the regular operators posted at their stations before operating a director, turret, or a gun from a dummy director.

5. Slew directors and guns only when it is necessary during practices.

6. All telephone stations should be manned when operating systems automatically or remotely.

7. Notify all operators and persons concerned before shifting a system to automatic control from local control.

8. Never operate directors, turrets, or guns in full automatic without having the regular operators posted at their stations.

9. Do not hesitate to stop any person from operating fire-control equipment if he may cause a casualty to himself, the equipment, or to any other person.

Electric Shock

Persons suffering from electric shock are often unconscious; the pulse is feeble and irregular and the breathing is slow and faint. The parts of the body that have come in contact with a live wire are sometimes burned or blistered.

The first, and most important thing to do for a person who has been shocked is to REMOVE THE PERSON from contact with the electric circuit or machine, or to cut the power supply. Disconnecting the power is the best bet if the power switch is located near the scene of the accident. However, in the event that cutting the power will waste time, you must remove the victim from contact with the circuit. This is always dangerous and should not be attempted until some means of insulating yourself is available. Your hands should be protected with rubber if possible, or several thicknesses of dry cloth. You should be further insulated by standing on a rubber mat if one is available at the scene, a pane of glass, or a dry board.

At the first opportunity, while you are making preparations to administer first aid, SEND FOR MEDICAL ASSISTANCE.

Artificial Respiration—Burns

For complete coverage of how to administer artificial respiration and how to treat burns, see *Standard First Aid Training Course*, NavPers 10081.

Be wise and observe all the safety regulations laid down in this chapter along with those contained in the *Bureau of Ordnance Manual*—remember, the life you save may be your own.

Conclusion

Now that you have completed this Navy Training Course you should have a good understanding of the basic principles underlying all fire-control gear. The mechanical and electrical diagrams you have studied give you the how of your equipment. No OP or OD on surface fire-control systems will stymie the man who has put some drive into his work on this course. It is keeping your gear in tiptop working operation that counts. That's why you need to understand the theory that lies behind the gear and now you should know it. Furthermore, you should be better prepared for the rating of Fire Control Technician 3.

QUIZ

Complete the following statements with the one or more required words:

1. Safety regulations which are applicable to ordnance equipment are located in the ____________ Manual.
2. The arc of an arc welder emits ____________ rays which can cause severe damage to the eyes.
3. The ____________ wire of portable electric tools should be connected to the ship's hull to prevent shock to the operator.
4. Never use metal hand tools on ____________ electric circuits or machines.
5. Never remove a ____________ from a running machine.
6. Always make sure everyone is clear before ____________ a machine.
7. Never try to ____________ a jammed machine without first cutting off its power.

8. Always guide a chain-fall hoist with ____________.
9. Whenever possible, operate electric switches and controls with ____________.
10. Never ____________ high-voltage protective devices on doors or covers.
11. Never use an incandescent test lamp unless its voltage rating is ____________ than the highest voltage to be tested.
12. Always turn on the ____________ bell before training in a turret.
13. Never operate a fire-control system in ____________ without having qualified operators at their stations.
14. Carelessness, one of the chief causes of accidents, can be overcome by the acquisition of
    a. experience
    b. overconfidence
    c. good working habits
    d. self-confidence
15. When using chipping, buffing, or grinding power tools, a man must wear
    a. eye goggles
    b. leather gloves
    c. a respiratory mask
    d. safety shoes
16. When it is necessary to work on high-voltage electric equipment in an energized state, it is mandatory to wear rubber gloves, to work with only one hand, to stand on a rubber mat, and to
    a. wear rubber eye goggles
    b. use tools with insulated handles
    c. wear rubber shoes
    d. wear a steel helmet
17. Before commencing work on a high-voltage circuit which has been deenergized, make sure that
    a. all synchros are on zero
    b. the inductance is zero
    c. all condensers are fully charged
    d. all condensers are fully discharged
18. Which of the following procedures should be followed before commencing work on an electrical circuit?
    a. First remove the fuzes and then check the condensers to see that they are fully charged
    b. First open the switch and then check the condensers to see that they are fully discharged
    c. First remove the fuzes, then tag the switchboard, and test the circuit with a voltage tester
    d. First tag the switch open at the switchboard, then remove the fuzes, and test the circuit with a voltage tester

19. What is the first and most important thing to do for a person who has been knocked unconscious by an electric shock?
    a. Remove his clothing.
    b. Send for medical assistance.
    c. Remove him from contact with the circuit
    d. Apply artificial respiration

APPENDIX I

PRIMARY BATTLE TELEPHONE CIRCUIT DESIGNATIONS

Circuit	*Designation*
JA	Captain's Battle Circuit.
1JB1–4	Turret Spotters, Group 1–4.
1JC	Turret Control.
2JC	Double Purpose Control.
4JC	Heavy Machine Gun Control.
5JC	Light Machine Gun Control.
JD	Unassigned.
JE	Unassigned.
JF	Flag Officers.
1JF	Navy Flag.
2JF	Air Recognition.
3JF	Air Distant Control.
4JF	Air Local Control.
5JF	Gun Fire Support.
6JF	Flag Information.
1JG	Aircraft Control.
2JG	Aircraft Information.
3JG	Aircraft Service.
5JG	Aviation Ordnance.
7JG	Conflagration Control.
JH	Switchboard Cross Connecting.
JI	Unassigned.
1JK1–4	Turret Fuzesetters, Computer 1–4.
1JK10–60	Turret Fuzesetters, Turret 1–6.
2JK1–4	Double Purpose Fuzesetters, Computer 1–4.
2JK10–180	Double Purpose Fuzesetters, Mount 1–18.
JL	Lookouts (Surface and Sky).
JM	Mine Control.
JN	Illumination Control.
JN1–4	Illumination Control, Group 1–4.

Circuit	*Designation*
JO	Switchboard Operators.
1JP1–4	Turret Control Group 1–4.
1JP10–60	Turret Control, Turret 1–6.
2JP1–6	Double Purpose Control, Group 1–6.
2JP10–180	Double Purpose Mount No. 1–18.
4JP1–25	Heavy Machine Gun Control, Group 1–25.
1JQ1–4	Turret Sightsetters, Computer 1–4.
1JQ10–60	Turret Sightsetters, Turret 1–6.
2JQ1–4	Double Purpose Sightsetters, Computer 1–4.
2JQ10–180	Double Purpose Sightsetters, Mount No. 1–18.
JR	Debarkation Control.
1JS	Combined Radar-Radio Information.
2JS	COC Interphone Circuit.
21JS	Search Radar No. 1.
22JS	Search Radar No. 2.
23JS	Search Radar No. 3.
24JS	Search Radar No. 4.
51JS	Radio Direction Finder.
61JS	Sonar Range and Bearing.
62JS	Sonar Depth.
81JS	Radar-Radio Countermeasure.
82JS	SupRad.
JT	Unassigned.
JU	Torpedo, Depth Charge.
9JU	Rocket Control.
1JV	Maneuvering, Docking and Catapult Control
2JV	Engineer's Circuit (Engines).
3JV	Engineer's Circuit (Boilers).
4JV	Engineer's Circuit (Fuel and Stability).
5JV	Engineer's Circuit (Electrical).
JW	Ship Control Rangefinders.
1JW1–4	Turret Range Control Group 1–4.
1JW10–60	Range Control, Turret 1–6.
2JW1–4	Double Purpose Range, Group 1–4.
2JW10–180	Double Purpose Mount No. 1–18.
JX	Radio and Signals.
JY	Unassigned.
2JZ	Damage and Stability Control.
3JZ	Upper Deck Repair.
4JZ	Forward Repair.
5JZ	After Repair.
6JZ	Amidships Repairs.

Circuit	*Designation*
7JZ	……Engineer's Repair.
8JZ	……Flight Deck Repair.
9JZ	……Magazine Sprinkling and Ordnance Repair Forward.
10JZ	……Magazine Sprinkling and Ordnance Repair Aft.
11JZ	……Superstructure Repair.
12JZ	……Fire Pump Control.

APPENDIX II

CIRCUIT DESIGNATIONS, COLOR CODE, NAVY CABLE, AND WIRING FITTINGS

The material contained herein will assist you in reading blue prints and wiring diagrams, and with trouble shooting and repairing fire control electric circuits. Although the information is by no means complete, the more important and useful material has been included.

CIRCUIT DESIGNATION (MAIN BATTERY)

NOTE.—Although the following designations depart somewhat from those used for dual-purpose and AA batteries, the circuit subdivision numbers (first number) is adhered to wherever possible for all systems.

GE—MAIN BATTERY CONTROL SYSTEM.—This system provides a general designation for the entire group of fire control circuits which are used in connection with control of major surface batteries including 6″, 8″, 12″, 14″, and 16″ turrets, except for double-purpose 6″ turrets (such as in CL144-145); GS designations are used for the latter systems. Circuit GE designations apply to wiring for instruments in turrets, plotting areas, directors, and control stations whose primary function is the control of the major surface battery. This is also a specific designation for the electrical wiring which supplies these circuits.

2GE—GUN TRAIN ORDER.—This system provides synchro transmission of gun train order to indicator dials at the trainer's station in turret. Source of such order may be a rangekeeper, computer, director, another turret, or local transmitter within the turret. (See circuit 2GEP for transmission to receiver regulator.) This designation has been used for cross level transmission in some vessels (for example BB55-60) but has since been superseded by designation 10GE for cross level transmission.

3GE.—Gun elevation order.—This system provides synchro transmission of gun elevation order to indicator dials at the pointer's or gun layer's station in turrets. Source of such order may be a rangekeeper, computer, director, another turret, or local transmitter within the turret. (See circuit 3GEP for transmission to receiver regulator.) This designation has been used for level transmission in some vessels (for example BB55-60) but has since been superseded by designation 50GE for level transmission.

4GE—Director-train angle.—This system provides synchro transmission of director-train angle (with or without trunnion-tilt correction) to rangekeeper or computer. This function may also be transmitted to turrets as gun train order and to various remote information indicators (in CIC, M.B. Control, Plot, other directors, Air Defense, Conn, Secondary Conn, Flag Plot, and Open Bridge). The primary purpose, however, is to provide accurate relative-target-bearing data to the computing device where it is used as a basis for developing gun train order.

5GE—Director elevation angle.—This system provides synchro transmission of director elevation angle to rangekeeper or computer. For surface fire this function is the equivalent of level transmission and the corresponding designation (50GE) has been used in some cases. However, where the main battery director is used for AA control (for example CA139 Class) the "5GE" designation is preferable.

6GE—Turret train.—This system provides synchro transmission of turret train angle. This function is received on turret train indicators throughout the ship, including own turret, on local computers within the turret and is transmitted to other turrets as "emergency gun train order."

7GE—Own ship course.—This system provides synchro transmission of own ship course from the main battery switchboard to main battery fire control instruments. Source of this order is the gyro compass system.

10GE—Cross level.—This system provides synchro transmission of cross level to rangekeepers, computers, directors, and stable verticals. Source of such order may be a stable element, stable vertical, or gun director.

13GE—FUZE-SETTING ORDER.—This system provides synchro transmission of fuze-setting order to indicator dials in turrets. The source of such order is a computer.

14GE—DIRECTOR TRAIN CONTROL.—This system provides synchro transmission of generated change in director train to the main battery switchboard. From switchboard this order is transmitted to indicator dials at the trainer's station in gun directors over circuit 16GE wires. Source of this order is a computer. (See circuit 14GEP for transmission to receiver regulators.

15GE—DIRECTOR ELEVATION CONTROL.—This system provides transmission of generated change in director elevation to the main battery switchboard. From the switchboard this order is transmitted to the indicator dials at the pointer's station in gun directors over circuit 50GE wires. Source of this order is a computer. (See circuit 15GEP for transmission to receiver regulators.)

16GE—DIRECTOR-TRAIN INFORMATION.—This system provides synchro transmission of director train to information receivers, such as bearing indicators or director-train indicators, which may be located in open bridge, primary conning station, flag plot, CIC, main-battery control stations, fire control tower, air-defense stations, and plotting rooms. Also, provides director-train information from other directors to indicating dials at the trainer's station in gun directors. (See also circuit 4GE.)

17GE—120-VOLT D.C. SUPPLY.—This system provides 120-volt D.C. supply to such main battery equipment as may require it.

19GE—SIGHT-ANGLE ORDER.—This system provides synchro transmission of sight-angle order to indicator dials at sight-setter's station in turrets and directors. Source of such order may be a rangekeeper or computer.

20GE—SIGHT-DEFLECTION ORDER.—This system provides synchro transmission of sight-deflection order to indicator dials at sight-setter's station in turrets and directors. Source of such order may be a rangekeeper or computer. Also, provides synchro transmission of sight-deflection order to antenna receiver regulator in turrets from local turret transmitters.

22GE—DEFLECTION SPOT.—This system provides synchro transmission of deflection spot from directors to computers.

23GE—ELEVATION SPOT.—This system provides synchro transmission of elevation spot from directors to computers.

24GE—INSTRUMENT AUXILIARY ILLUMINATION, (6-volt Battery) —This system provides 6-volt d.c. supply from a local battery for auxiliary illumination supply to main battery instruments.

25GE—TRAIN PARALLAX.—This system provides synchro transmission of parallax range or unit parallax to receivers in turrets, or gun directors. Source of such order is a rangekeeper or computer. In some vessels this function has been designed as 29 GE for transmission to directors.

27GE—INSTRUMENT HEATER AND SUPPLY.—This system provides 120-volt a.c. supply to heater elements in main-battery fire control instruments.

31GE—OBSERVED RANGEFINDER RANGE.—This system provides synchro transmission of rangefinder (optical) range to various range receivers. These may be integral with computers and rangekeepers or they may be range indicators in plot. The source of such range transmission may be rangefinders in gun directors or in turrets. Transmission from turrets is obsolescent and will be removed with removal of graphic plotters in rangekeepers.

32GE—RANGE CONTROL.—This system provides synchro transmission of generated change in range from computers or rangekeepers to fire control switchboard and gun directors. From fire control switchboard this order may be transmitted as 32PE to fire control radar console.

33GE—RANGE SPOT.—This system provides synchro transmission of range spot from directors to computers.

36GE—GENERATED DIRECTOR TRAIN.—This system provides synchro transmission of generated director train to various receivers. Such receivers may be located in directors, stable verticles, and rangekeepers. Source of transmission is a rangekeeper.

37GE—TARGET COURSE.—This system provides synchro transmission of target course from a computer to a nearby control instrument. Slewing buttons at the control instrument are used to enter target course into the computer and simultaneously position the computer transmitter.

50GE –LEVEL ANGLE.—This system provides synchro transmission of level angle to receivers in directors, stable verticals, antenna mounts, and rangekeepers. Source of such transmission may be a gun director or stable vertical.

51GE—CONTROL TRANSFER SIGNAL.—This system provides, in vessels with duplicate fire control switchboards, a visual indication at each transfer switch (which selects either switchboard) to show the switchboard to which that transfer switch should be connected. An indicator panel is provided in each plotting room to show the manner in which the remote stations are connected to each fire control switchboard. A local buzzer circuit is provided at each transfer switch or group of transfer switches to indicate when any switch of the group is not positioned correctly.

52GE—GUN TRAIN ORDER INFORMATION.—This system provides synchro transmission of gun train order for use in energizing the zero reader of multiple turret train indicators. The source of such transmission may be a synchro in a rangekeeper or computer or a gun train order relay transmitter.

GEL—MISCELLANEOUS A. C. SUPPLY CIRCUIT.—This system provides 120-volt a.c. to various main battery instruments, such as rangekeepers, computers, stable elements, stable verticle and directors. Such supply may be used for servos, amplifiers, internal illumination, or mark signals.

1GEL—ILLUMINATING SUPPLY (6-VOLT).—This system provides 6-volt supply to energize illumination circuits in main battery instruments. Generally a selection is made from the 6-volt output of an illumination transformer or a standby storage battery. (See circuit 24GE.)

GEP—MAIN BATTERY REMOTE CONTROL SYSTEM.—This system provides a general designation for interconnections between instruments used for remote or automatic control of the major caliber surface battery, including 6″, 8″, 12″, 14″, and 16″ turrets. This system for automatic control is the counterpart of the GE systems for indicating control. (See circuit GE.)

2GEP—GUN TRAIN ORDER.—This system provides synchro transmission of gun train order to train receiver regulators in turrets. Source of such order may be a rangekeeper, computer, director, another turret, or local transmitter within the turret. (See circuit 2GE for transmission to indicators.)

3GEP—GUN ELEVATION ORDER.—This system provides synchro transmission of gun-elevation order to elevation receiver regulators in turrets. Source of such order may be a range keeper, computer, director, another turret, or local transmitter within the turret (See circuit 3GE for transmission to indicators.)

4GEP—DIRECTOR-TRAIN ANGLE.—This system provides automatic synchro input of director-train angle to range keeper or computer. This designation is applied to wires for servos associated with direct-train synchros.

5GEP—DIRECTOR ELEVATION.—This system provides automatic synchro input of director-elevation angle to rangekeeper or computer. This designation is also applied to wires for servos associated with director-elevation synchros.

7GEP—OWN SHIP COURSE.—This system provides servo follow-up of own ship course inputs in rangekeepers, computers, stable element and stable vertical panels. (See circuit 7 GE.)

10GEP—CROSS LEVEL.—This system provides servo follow-up of cross level inputs in rangekeepers and stable verticals. (See circuit 10 GE.)

13GEP—FUZE-SETTING ORDER.—This system provides synchro transmission of fuze-setting order to receiver regulators in turrets. The source of such order is a computer. This designation is also applied to wires for servos associated with fuze-setting synchros.

14GEP—DIRECTOR-TRAIN CONTROL.—This system provides synchro transmission of generated change in director train to receiver regulators in directors. The source of such order may be a rangkeeper or computer. This designation is also applied to servo and control wires associated with director-train-control equipment.

15GEP—DIRECTOR ELEVATION CONTROL.—This system provides synchro transmission of generated change in director elevation to receiver regulators in directors. The source of such order may be computer or stable vertical. This designation is also applied to servo and control wires associated with director elevation control equipment.

50GEP—LEVEL-ANGLE ORDER.—This system provides servo follow-up of level-angle inputs in rangekeeper, stable verticals, directors, and antenna mounts. (See circuit 50GE.)

CONDUCTOR COLOR CODE

The following color code is used in Navy-type electrical I.C. and F.C. Cables.

Wire No.	Base Color	Tracer Color	Tracer Color	Wire No.	Base Color	Tracer Color	Tracer Color
1	Black			23	White	Black	Red
2	White			24	Red	Black	White
3	Red			25	Green	Black	White
4	Green			26	Orange	Black	White
5	Orange			27	Blue	Black	White
6	Blue			28	Black	Red	Green
7	White	Black		29	White	Red	Green
8	Red	Black		30	Red	Black	Green
9	Green	Black		31	Green	Black	Orange
10	Orange	Black		32	Orange	Black	Green
11	Blue	Black		33	Blue	White	Orange
12	Black	White		34	Black	White	Orange
13	Red	White		35	White	Red	Orange
14	Green	White		36	Orange	White	Blue
15	Blue	White		37	White	Red	Blue
16	Black	Red		38	Brown		
17	White	Red		39	Brown	Black	
18	Orange	Red		40	Brown	White	
19	Blue	Red		41	Brown	Red	
20	Red	Green		42	Brown	Green	
21	Orange	Green		43	Brown	Orange	
22	Black	White	Red	44	Brown	Blue	

NAVY CABLES AND FITTINGS

Insulated Cables For Fixed Installations
Rubber Insulation

BC	Bell cord.
BW	Bell wire.
DLB	Double lighting braided.
DLPA	Double lighting and power armored.
DRHLA	Double, radio, high-tension, leaded and armored.
DRLL	Double, radio, low-tension, leaded.
FLA	Four-conductor, lighting, armored.
FLB	Four-conductor, lighting, braided.
GICA	General interior communication, armored.
SICP	Single, instrument cable, plain.
SLPA	Single, lighting and power, armored.
SRHLA	Single, radio, high-tension, leaded and armored.
SRLL	Single, radio, low-tension, leaded.
TLPA	Triple, lighting and power, armored.
TPTA	Twisted pair telephone, armored.
TRHLA	Triple, radio, high-tension, leaded and armored.
TRLL	Triple, radio, low-tension, leaded.
VLS	Voltmeter leads, (submarines).

Rubber Insulated Flexible

DCP	Double conductor portable.
DCOP	Double conductor, oil resistant, portable.
FCP	Four conductor, portable.
FCOP	Four conductor, oil resistant, portable.
GICF	General, interior communication, flexible.
MCMB	Multiple conductor, marker buoy.
MCP	Multiple conductor, portable.
MCS	Multiple conductor, shielded.
MCOS	Multiple conductor, oil resistant, shielded.
SCP	Single conductor, portable.
SCOP	Single conductor, oil resistant, portable.
TCP	Triple conductor, portable.
TCOP	Triple conductor, oil resistant, portable.
TPTF	Twisted pair telephone, flexible.
TPTP	Twisted pair telephone, plain.
MCOP	Multiple conductor, oil resistant, portable.
TTOP	Twisted pair telephone, oil resistant, portable.

Heat - And Flame-Resistant Insulation

DHFA	Double conductor, heat- and flame-resistant, armored.

DHFW	Double, heat- and flame-resistant, wire.
FHFA	Four conductor, heat- and flame-resistant, armored.
MDGA	Multiple conductor, degaussing, armored.
MHFA	Multiple conductor, heat- and flame-resistant, armored.
MHFF	Multiple conductor, heat- and flame-resistant, flexible.
SDGA	Single conductor, degaussing, armored.
SHFA	Single conductor, heat-and flame-resistant, armored.
SHFL	Single conductor, heat- and flame-resistant, leaded.
SHFS	Single conductor, heat- and flame-resistant, switchboard.
SHFW	Single, heat- and flame-resistant, wire.
SFPS	Single, flameproof, switchboard.
SRI	Synthetic resin insulated.
SRIB	Synthetic resin insulated, braided.
SRIG	Synthetic resin insulated, glass braid.
THFA	Triple conductor heat- and flame-resistant, armored.
TTHFA	Twisted pair, telephone, heat- and flame-resistant, armored.
TTHFF	Twisted pair, telephone, heat- and flame-resistant, flexible.

STEEL TERMINAL TUBE INFORMATION

Tube Size	Tube Clearance Drill Size	I. D. Packing Gland	Tube Size	Tube Clearance Drill Size	I. D. Packing Gland
A	$\frac{9}{16}$	$\frac{13}{32}$	N	$1\frac{3}{4}$	$1\frac{17}{32}$
B	$\frac{11}{16}$	$\frac{17}{32}$	P	$1\frac{7}{8}$	$1\frac{5}{8}$
C	$\frac{13}{16}$	$\frac{21}{32}$	R	2	$1\frac{25}{32}$
D	$\frac{15}{16}$	$\frac{25}{32}$	S	$2\frac{1}{8}$	$1\frac{29}{32}$
E	1	$\frac{27}{32}$	T	$2\frac{3}{8}$	$2\frac{1}{16}$
F	1	$\frac{7}{8}$	V	$2\frac{1}{2}$	$2\frac{3}{16}$
U		$\frac{29}{32}$	W	$2\frac{11}{16}$	$2\frac{5}{16}$
G	$1\frac{1}{8}$	$\frac{31}{32}$	X	$2\frac{13}{16}$	$2\frac{1}{2}$
J	$1\frac{1}{4}$	$1\frac{1}{16}$	Y	$2\frac{15}{16}$	$2\frac{5}{8}$
K	$1\frac{3}{8}$	$1\frac{5}{32}$	Z	$3\frac{1}{8}$	$2\frac{13}{16}$
			Z-1		3
L	$1\frac{7}{16}$	$1\frac{1}{4}$	AA	$3\frac{3}{16}$	$2\frac{29}{32}$
M	$1\frac{9}{16}$	$1\frac{13}{32}$	BB	$3\frac{7}{16}$	$3\frac{1}{8}$

CABLE CONSTRUCTION

SFPS (up to 100,000 CM)	SHFA (up to 800,000 CM)
(A) Copper	(A) Copper
(B) Varnished Cambric	(B) Felted Asbestos
(C) Felted Asbestos	(C) Varnished Cambric
(D) Cotton Braid	(D) Felted Asbestos
	(E) Heat Impervious Sheath
	(F) Armor

DHFA and THFA		MHFA
(A) Copper	conductor	(A) Copper
(B) Felted Asbestos		(B) Felted Asbestos
(C) Varnished Cambric		(C) Rayon or Cellulose Acetate Color Code braid, and flame-retarding compound.
(D) Felted Asbestos		(D) Cellophane Wrapping
(E) Felted Asbestos	cable	(E) Felted Asbestos
(F) Special Heat Impervious Sheath		(F) Special Heat Impervious Sheath
(G) Armor		(G) Armor

APPENDIX III

ANSWERS TO QUIZZES

CHAPTER 1

THE FIRE-CONTROL ORGANIZATION

1. d. Gunnery officer
2. e. Turret officer
3. c. CIC officer
4. e. Turret officer
5. b. Group control officer
6. a. Air defense officer
7. e. Turret officer
8. a. Air defense officer
9. b. Ammunition control
10. d. Direct fire-control problem arising under combat conditions
11. a. Executive officer
12. b. Gunnery officer
13. c. In the fire-control tower
14. d. Main battery only
15. a. At the director
16. a. Chief fire-control officer
17. c. 4
18. d. Protection at every angle
19. c. *Mathematics*, NavPers 10070–A
20. d. *Electricity*, NavPers 10622–B
21. a. *Basic Machines*, NavPers 10624
22. b. *Basic Hand Tool Skills*, NavPers 10085
23. a. *Basic Machines*, NavPers 10624
24. d. *Electricity*, NavPers 10622–B
25. d. *Electricity*, NavPers 10622–B
26. e. *Blueprint Reading*, NavPers 10077
27. f. *General Training Course for PO's*, NavPers 10602–A
28. d. *Electricity*, NavPers 10622–B

CHAPTER 2

PREVIEW OF THE FIRE-CONTROL PROBLEM

1. c. Distance to the horizon
2. a. In the plotting room
3. a. On a high point above deck
4. d. Relative motion
5. d. Computer
6. b. Gun
7. a. The director
8. d. All three of the above
9. c. Ship's compass and pitometer log
10. a. Roll and pitch of ship
11. c. Sight angle and deflection
12. c. Elevation
13. b. Bearing
14. d. Sight angle and sight deflection

CHAPTER 3

MECHANICAL COMPONENTS

1. c. To step up power
2. c. Inner race
3. b. Bearings
4. a. Join shafts that lie in the same straight line
5. d. Permit fastening the sleeve securely to both shafts with clamps
6. b. Temperature changes cause changes in shaft lengths
7. a. Lie at an angle to each other
8. b. Reduce shaft vibration
9. c. Straight spur gears
10. d. Spur gears
11. b. Couple
12. c. Driver gear
13. b. Driven gear
14. d. An idler gear
15. b. 1:3
16. c. A spiral gear
17. c. Save space and material
18. c. 90°
19. c. 24:1
20. d. Worm and worm wheel
21. b. Reduce error
22. a. Holding friction
23. d. Plunger
24. a. ¼ turn

CHAPTER 4

BASIC MECHANISMS

1. b. Plus 5 turns
2. d. Minus 5 turns
3. c. Minus 2½ turns
4. b. Zero
5. a. Plus 20 turns
6. a. Plus 30 turns
7. c. The other end gear rotates an equal amount in the opposite direction
8. a. Shift gear is up
9. a. Ballistic cam
10. d. Range and elevation
11. b. Constant-lead
12. d. Tangent
13. c. 70°.
14. a. 90°.
15. d. Barrel
16. b. *Tf* decreases
17. b. *Tf* decreases

CHAPTER 5

GYROSCOPES

1. c. Gyroscopic stability
2. a. Forces which tend to tilt the gyro wheel
3. d. Gyroscopic stability
4. b. Tilt to the west
5. b. 15°
6. c. Equator
7. a. North pole
8. b. Correct positions for any latitude
9. d. Counteract the westward tilt of the gyro
10. a. North
11. a. Mercury ballistic tanks and gimbal rotation
12. c. Gyro erection system
13. c. Amount of precession
14. c. Momentum of the spinning wheel and the applied force
15. b. Rotated at the same constant speed

CHAPTER 6

LEAD-COMPUTING SIGHTS

1. Present range
2. Counterbalanced
3. Speed
4. Trunnion
5. Lags
6. Reticle image
7. Traverse; elevation
8. Inversely
9. Present range
10. Negative
11. Multiply or amplify
12. Weight; output axis
13. Tilted
14. No
15. Trunnion; reticle
16. b. Decreased
17. a. Steady
18. c. Range
19. b. Reticle block
20. a. Gyro wheels
21. 2¼ p. s. i.
22. b. Fresh water

CHAPTER 7

MAINTAINING F-C CIRCUITS

1. T
2. T
3. F
4. F
5. T
6. T
7. Stuffing or terminal
8. Deck
9. Wires or leads
10. Moisture
11. Disconnected or deenergized or dead open
12. Five
13. c. Highest
14. a. Its high conductance causes grounds
15. b. The number of terminals they contain
16. b. Megger
17. a. Open circuits

18. c. Main battery
19. d. Dual-purpose battery
20. d. 3GEP
21. d. 4GE
22. c. 7GEP
23. c. Orange
24. d. White base with black tracers
25. a. Wires #1 to 6
26. b. Multiple conductor, is heat and flame resistant, and is armored
27. d. Triple conductor, is oil resistant, and is portable

CHAPTER 8

SYNCHRO TRANSMITTERS AND RECEIVERS

1. a. Own ship's speed
2. c. To transmit information
3. a. Transmitter
4. a. Electrical energy to mechanical energy
5. c. Master gyro
6. c. The mechanical load is kept light
7. d. Computer to the gun
8. c. Power drive unit
9. a. Three-phase star-connected generator
10. a. Rotor
11. c. Five
12. d. Brush slip-ring system
13. d. An oscillation damper
14. c. To prevent oscillation
15. c. A transformer
16. Single-phase a–c
17. a. 0°
18. b. Cosine of the rotor displacement angle
19. c. 115 v-a-c
20. a. 52 v.
21. b. Bucking transformers
22. c. 26 v.
23. a. 0 v.
24. c. *S2* winding
25. d. Magnitude, phase, and frequency
26. d. *S1* of the receiver
27. c. Receiver rotor and the receiver stator
28. c. Signal
29. d. 360°
30. c. Current in the receiver stator is zero
31. b. The torque of the receiver shaft decreases to zero at correspondence

CHAPTER 9

SAFETY PRECAUTIONS

1. Bureau of Ordnance
2. Ultra violet
3. Ground
4. Energized
5. Guard or cover
6. Starting or operating
7. Clear or free
8. Guide lines
9. One hand
10. Block
11. Greater
12. Warning
13. Automatic
14. c. Good working habits
15. a. Eye goggles
16. b. Use tools with insulated handles
17. d. All condensers are fully discharged
18. d. First tag the switch open at the switchboard, then remove the fuses, and test the circuit with a voltage tester
19. c. Remove him from contact with the circuit

APPENDIX IV

QUALIFICATIONS FOR ADVANCEMENT IN RATING

FIRE CONTROL TECHNICIANS (FT)

RATING CODE NO. 0800

General Service Rating

Scope

Fire control technicians maintain and repair fire control systems, including fire control radars and target designation equipment; make detailed mechanical, electrical, and electronic casualty analyses; test, operate, clean, lubricate, inspect, adjust, and calibrate fire control units; remove, repair, replace, and install or reassemble fire control components and systems; make transmission, computing, and rate tests on fire control systems; boresight guns and aline guns or launchers and fire control systems.

Emergency Service Ratings

Fire Control Technicians A (Automatic Directors), Rating Code No. 0804	FTA
Maintain and repair fire control systems Mk 37, Mk 56, Mk 68, Mk 69, Gunars, surface fire control systems for calibre 6'' and above, and associated equipment.	
Fire Control Technicians M (Manually Controlled Directors), Rating Code No. 0802	FTM
Maintain and repair fire control systems Mk 52, Mk 57, Mk 63, Mk 70, and Mk 51 director, and associated equipment.	
Fire Control Technicians U (Underwater), Rating Code No. 0803	FTU
Maintain and repair fire control systems Mk 101, Mk 102, Mk 104, Mk 105, and Mk 106 or individual components thereof, and associated equipment.	
Fire Control Technicians G (Missile Guidance Systems), Rating Code No. 0801	FTG
Maintain and repair guided missile fire control systems and associated equipment.	

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classifications, NavPers 15105 (Revised), codes FT–1100 to FT–1199.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
100 PRACTICAL FACTORS					
101 OPERATIONAL					
1. Demonstrate, under simulated conditions, the rescue of a person in contact with an energized electrical circuit; resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
2. Read dials and set operating controls to predetermined values on fire control equipment	3	3	3	3	3
3. Demonstrate on fire control equipment to which assigned, operating procedures and techniques as required to:					
a. Perform operator's adjustments	3	3	3	3	3
b. Perform transmission, computing, and rate tests and report and record results	3	3	3	3	3
4. Demonstrate on target designation equipment of own ship, operating procedures and techniques required to:					
a. Perform operator's adjustments	3	3	3	--	3
b. Test and interpret qualitative performance of designate and repeatback channels	2	2	2	--	2
5. Compute corrections to compensate for operator and rangefinder errors	1	1	--	--	--

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
101 OPERATIONAL—Continued					
6. Demonstrate operating procedures and techniques on fire control equipment to which assigned, as required to train battle station and watch standing operators	C	C	C	C	C
7. Demonstrate operating procedures and techniques on target designation equipment of own ship as required to train battle station and watch standing operators	C	C	C	--	C
8. Compute ballistics using standard forms and work sheets	C	C	C	--	--
102 MAINTENANCE AND/OR REPAIR					
1. Identify electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment	3	3	3	3	3
2. Identify capacitors and resistors by RMA color codes	3	3	3	3	3
3. Lubricate fire control equipment in accordance with lubrication charts	3	3	3	3	3
4. Make tests of electrical fire control circuits for continuity, grounds, and short circuits	3	3	3	3	3
5. Inspect and clean commutator and slip ring assemblies and replace brushes	3	3	3	3	3
6. Make prescribed electronic tests of servo and computing circuits, using multimeters, tube testers, and cathode ray oscilloscopes, and report results	3	3	3	3	3
7. Make operator's adjustments and checks to fire control radars	3	3	3	--	3
8. Conduct shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3	--	--

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR—Con.					
9. Trace circuits through fire control and sound-powered telephone switchboards and make repairs as necessary	2	2	2	2	2
10. Perform all tests and adjustments necessary for proper operation of servo and computing circuits. Test synchros, interconnecting circuits, and switchboards and set synchros to electrical zero	2	2	2	2	2
11. Prepare a gun, launcher, director station, or target designation system for battery alinement (afloat) by alining synchros and setting mechanical dials to reference points	2	2	2	--	2
12. Make internal adjustments and calibrations to fire control radars	2	2	2	--	2
13. Make standard electronic tests of radar circuits, using signal generators, multimeters, tube testers, and cathode ray oscilloscopes, and report results	2	2	2	--	2
14. Perform all shipboard maintenance on rangefinders not requiring the services of an opticalman	2	2	--	--	--
15. Prepare underwater fire control systems for battery alinement (afloat) by alining synchros and setting mechanical dials to reference points	--	--	--	2	--
16. Trace circuits and test synchros and servomechanisms and make replacements, adjustments, and repairs	1	1	1	1	1
17. Test, remove, replace, and adjust mechanical parts of fire control and/or torpedo control equipment	1	1	1	1	1
18. Analyze failures and make repairs to servo and computing circuits	1	1	1	1	1

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR—Con.					
19. Lubricate and perform shipboard adjustments to gyroscopes used in fire control equipment	1	1	1	1	1
20. Conduct battery alinement tests and evaluate results	1	1	1	--	1
21. Boresight guns and aline guns or launchers, directors, fire control radar antennas, torpedo fire control directors and indicators on tube mount, and target designation equipment. Test firing cut-out devices for proper operation	1	1	1	--	1
22. Perform all tests and adjustments necessary for proper operation of radar circuits	1	1	1	--	1
23. Aline underwater fire control systems. Test firing and firing cut-out devices for proper operation	--	--	--	1	--
24. Analyze results of transmission, alinement, computer, and rate tests to determine need for adjustment, replacement of parts, or repairs	C	C	C	C	C
25. Conduct all electrical tests on a complete fire control system	C	C	C	C	C
26. Analyze failures and effect repairs to target designation equipment	C	C	C	--	C
27. Conduct battery alinement and compute and apply corrections	C	C	C	--	C
28. Analyze failures and effect repairs to fire control systems	C	C	C	C	C
29. Analyze results of dummy director and error recorder tests and effect necessary repairs and adjustments	C	C	C	--	C
30. Conduct underwater fire control alinement and compute and apply corrections	--	--	--	C	--

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
103 ADMINISTRATIVE AND/OR CLERICAL					
1. Keep rough logs of periodic tests and maintenance	3	3	3	3	3
2. Make failure reports and keep ordnance histories	2	2	2	2	2
3. Use Ordnance Stock Catalogue	2	2	2	2	2
4. Maintain a Current Ship's Maintenance Project (CSMP) and prepare naval shipyard and tender work requests or job orders	C	C	C	C	C
5. Maintain supplies and spare parts and obtain replacements	C	C	C	C	C
200 EXAMINATION SUBJECTS					
201 OPERATIONAL					
1. Interpretation and interpolation of a dial setting into minutes, degrees, yards, or mils	3	3	3	3	3
2. Effects of electrical shock; method of resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
3. Given course and speed of own ship and target, solve analytically for range rate and linear deflection (bearing) rate	2	2	2	2	2
4. Given course and speed of own ship and course, speed, and elevation of air target, solve analytically for range rate, linear deflection (bearing) rate, and linear elevation rate	1	1	1	--	1
5. Operating principles of stereo rangefinders. Methods used to measure operator and rangefinder errors and methods used to compute corrections	1	1	--	--	--
6. Variables and constants of initial ballistics	C	C	C	--	--
7. Elements of air and surface fire control problems	C	C	C	--	C

Qualifications for Advancement in Rating	Applicable Rates				
	FT	FTA	FTM	FTU	FTG
201 OPERATIONAL—Continued					
8. Variables and constants of underwater ballistics	C	--	--	C	--
9. Elements of underwater fire control problems	C	--	--	C	--
202 MAINTENANCE AND/OR REPAIR					
1. Types of information shown and meanings of electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment excluding fire control quantities	3	3	3	3	3
2. RMA color coding systems for capacitors and resistors	3	3	3	3	3
3. Precautions to be observed in lubricating fire control equipment	3	3	3	3	3
4. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3	3	3	3	3
5. Methods of testing resistors, potentiometers, coils, transformers, capacitors, and electron tubes and application of each in voltage amplifier, phase inverter, power supply, oscillator, power amplifier, and rectifier circuits. Recognize electronic stages, power supply circuits, and coupling circuits	3	3	3	3	3
6. Function of each of the elements in gas-filled, vacuum, and cathode ray tubes	3	3	3	3	3
7. Calculate current, voltage, phase angle, impedance, and resistance in series and parallel circuits containing not more than a combination of four elements	3	3	3	3	3
8. Purposes of the following fire control radar operator's adjustments and checks: Intensity, sweep, focus, centering, receiver gain, re-					

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
202 MAINTENANCE AND/OR REPAIR—Con.					
ceiver tuning, video gain, modulator frequency, range slew, range and train, and elevation zero checks	3	3	3	--	3
9. Properties of free and restrained gyroscopes and purpose of damping	3	3	3	--	3
10. Purpose and interpretation of shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3	--	--
11. Purposes of transmission, computing, and rate tests	3	3	3	3	3
12. Types, operating principles, and application of switching gear used in fire control and sound-powered telephone switchboards	2	2	2	2	2
13. Characteristics and use of synchros and methods of setting to electrical zero	2	2	2	2	2
14. Operating principles (excluding knowledge required *only* in research, engineering, and manufacture) of the following: Tuned coupling circuits, impedance matching, cathode followers, modulators and demodulators, oscillators, phase shifters, mixers, heterodyning, automatic gain control, frequency modulation, discriminators, automatic frequency control, integration and differentiation, counting circuits, saw-tooth generators, multivibrators, limiters, peakers, clampers, and half- and quarter-wave antennas	2	2	2	2	2
15. Methods of making gain, phase, balancing, bias, and zeroing ad-					

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
202 MAINTENANCE AND/OR REPAIR—Con.					
justments of servo-loops found in computing and power-drive circuits	2	2	2	2	2
16. Use of tram bar, method of setting synchros to electrical zero, and method of positioning shafts by adjustable couplings	2	2	2	2	2
17. Types, application, and operating principles of electromechanical servomechanisms	1	1	1	1	1
18. Purpose, operating principles, and adjustments of basic fire control mechanisms	1	1	1	1	1
19. Operating principles of computing circuits, servo-loops, and power-drive circuits	1	1	1	1	1
20. Method of mounting and alining a boresight telescope on a gun or launcher. Purpose and method of alining sights to gun bore. Purpose and method of checking a director to a reference plane and reference point. Quantities set on inclination compensators. Methods for conducting train and elevation checks (afloat)	1	1	1	--	1
21. Purpose and operating principles of the following radar circuits: Transmitter, video amplifier, modulation generator, range unit, indicator unit, echo box, dummy antenna, power supply, waveguides, antennas, voltage regulator, transmission lines, IF amplifier, RF amplifier, or preselector	1	1	1	--	1
22. Method of setting up and purpose of dummy director and error recorder tests; information obtained and interpretation of results	1	1	1	--	1
23. Method of alining underwater fire control systems	C	--	--	1	--

	Qualifications for Advancement in Rating	*Applicable Rates*				
		FT	FTA	FTM	FTU	FTG
201	OPERATIONAL—Continued					
	24. Purpose and method of the following radar checks: Double echo, receiver sensitivity, standing wave ratio, and transmitted power level	C	C	C	--	C
	25. Methods used in battery alinement (afloat and drydock). Use of gunner's quadrant. Method and purpose of static alinement. Principles involved in establishing bench mark and tram points. Method of computation of roller path inclination from horizon checks. Methods of train and elevation checks (afloat)	C	C	C	--	C
	26. Relationship of electrical and mechanical inputs and outputs of a radar, rangefinder, director, computer, stable element, and gun mount of a dual purpose battery	C	C	C	--	--
	27. Relationship of electrical and mechanical inputs and outputs of a launcher and missile fire control system	C	--	--	--	C
203	ADMINISTRATIVE AND /OR CLERICAL					
	1. Types, purpose of, and entries made in rough logs	3	3	3	3	3
	2. Purposes and types of entries made in failure reports and ordnance histories	2	2	2	2	2
	3. Types of information found in the following publications: Ordnance Pamphlets, Ordnance Data, Ordnance Circular Letters, Ordnance Handling Instructions, Ordnance Modification Instructions, Ordnance Material Letters, Ordnance Alterations, NavOrd Instructions, and NavOrd Notices	2	2	2	2	2
	4. Purpose and scope of BuOrd Manual as stated in chapter 1	1	1	1	1	1

Qualifications for Advancement in Rating	Applicable Rates				
	FT	FTA	FTM	FTU	FTG
202 ADMINISTRATIVE AND/OR CLERICAL—Continued					
5. Information shown in Current Ship's Maintenance Project (CSMP), naval shipyard, and tender work request or job order	C	C	C	C	C
6. Physical requirements for range-finder operators	C	C	--	--	--

300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER

Fire Control Technicians advance to Warrant Control Ordnance Technician and/or to Limited Duty Officer, Ordnance. As an alternate, Fire Control Technicians advance to Warrant Electronics Technician and/or to Limited Duty Officer, Electronics.

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